

DOT POINT

VISIT...

IB PHYSICS AHL



hargava



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Introduction

What the book includes

This book provides questions and answers for each dot point in the IB Physics AHL syllabus from the International Baccalaureate Diploma Programme for Physics:

- Motion in Fields
- Thermal Physics
- Wave Phenomena
- Electromagnetic Induction
- Quantum Physics and Nuclear Physics
- Digital Technology

Format of the book

The book has been formatted in the following way:

1.1 Subtopic from syllabus.

1.1.1 Assessment statement from syllabus.

1.1.1.1 First question for this assessment statement.

1.1.1.2 Second question for this assessment statement.

The number of lines provided for each answer gives an indication of how many marks the question might be worth in an examination. As a rough rule, every two lines of answer might be worth 1 mark.

How to use the book

Completing all questions will provide you with a summary of all the work you need to know from the syllabus. You may have done work in addition to this with your teacher as extension work. Obviously this is not covered, but you may need to know this additional work for your school exams.

When working through the questions, write the answers you have to look up in a different colour to those you know without having to research the work. This will provide you with a quick reference for work needing further revision.

Command Terms and Verbs to Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Use an idea, equation, principle, theory or law in a new situation.

assess Make a judgement of value, quality, outcomes, results or size.

calculate Find a numerical answer showing the relevant stages in the working (unless instructed not to do so).

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

deduce Reach a conclusion from the information given.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Give an account including, where possible, a range of arguments for and against the relative importance of various factors, or comparisons of alternative hypotheses.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Give a detailed account of causes, reasons or mechanisms.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

identify Find an answer from a given number of possibilities.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers with no explanation.

measure Find a value for a quantity.

outline Give a brief account or summary.

predict Give an expected result.

propose Put forward a point of view, idea, argument, suggestion etc for consideration or action.

recall Present remembered ideas, facts or experiences.

show Give the steps in a calculation or derivation.

sketch Represent by means of a graph showing a line and labelled but unscaled axes but with important features (for example, intercept) clearly indicated.

solve Obtain an answer using algebraic and/or numerical methods.

state Give a specific name, value or other brief answer without explanation or calculation.

suggest Propose a hypothesis or other possible answer.

summarise Express concisely the relevant details.

synthesise Put together various elements to make a whole.

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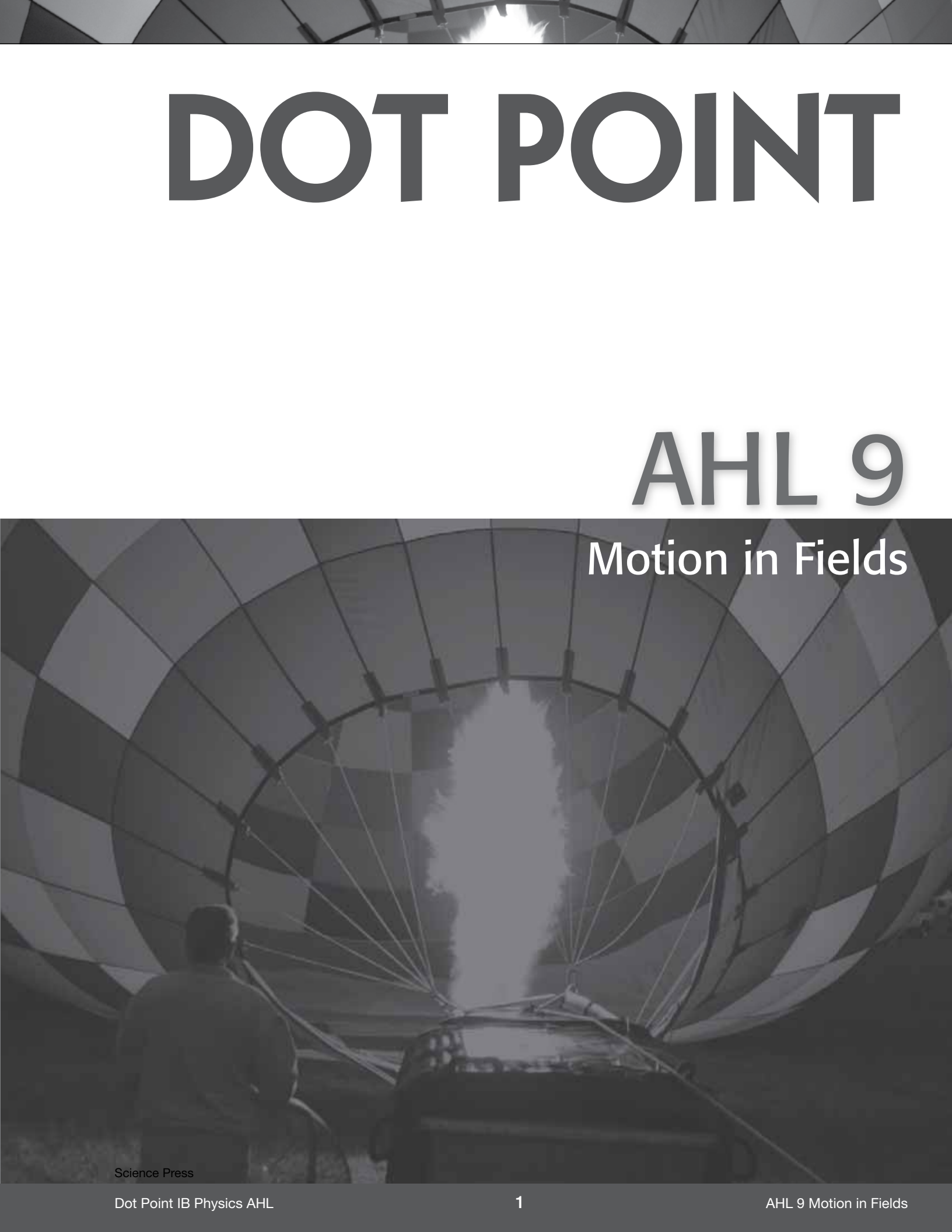
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AHL 9

Motion in Fields

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9.1

Projectile motion. © IBO 2007

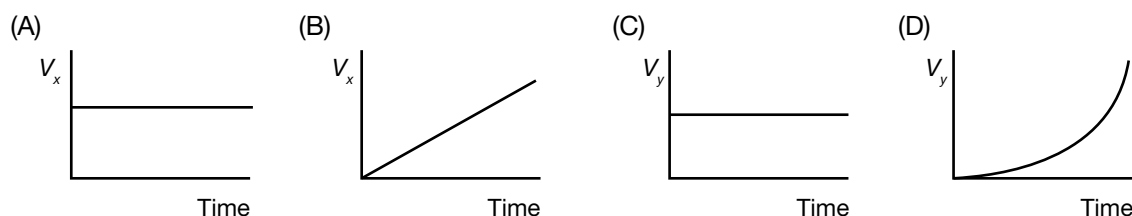
9.1.1 State the independence of the vertical and the horizontal components of velocity for a projectile in a uniform field. © IBO 2007

9.1.1.1 Which of the following statements about projectile motion is correct?

- (A) The horizontal distance a projectile travels is proportional to the time of travel squared.
- (B) The rate at which a projectile rises and falls is proportional to its mass.
- (C) The square of the distance a projectile travels is proportional to the time of flight.
- (D) The rate at which a projectile rises and falls is independent of its velocity.

Extension: Justify your answer.

9.1.1.2 Which of the following graphs about the components of projectile motion is correct?



Extension: Recall Galileo's three statements about projectile motion.

9.1.1.3 Which of the following statements is in agreement with Galileo's analysis of projectile motion?

- (A) The rate at which a projectile falls is proportional to its mass.
- (B) The range of the projectile is proportional to the time elapsed.
- (C) The range of the projectile is proportional to its initial vertical speed.
- (D) The speed of the projectile is the vector sum of the vertical and horizontal components of that speed.

Extension: Explain how your choice relates to Galileo's analysis.

9.1.1.4 Which of the following statements was *not* one of Galileo's descriptions of projectile motion?

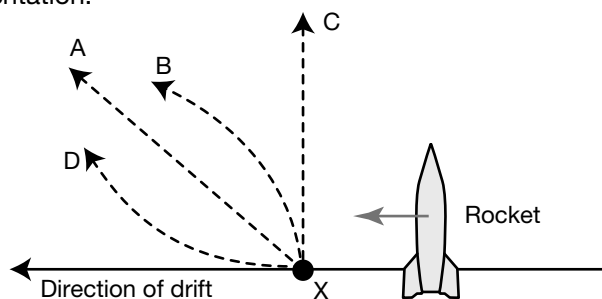
- (A) Horizontal motion is constant.
- (B) Horizontal acceleration is zero.
- (C) Vertical motion is accelerated.
- (D) Vertical acceleration is negative.

9.1.1.5 A rocket is drifting in space at right angles to its orientation.

At point X it fires its rockets.

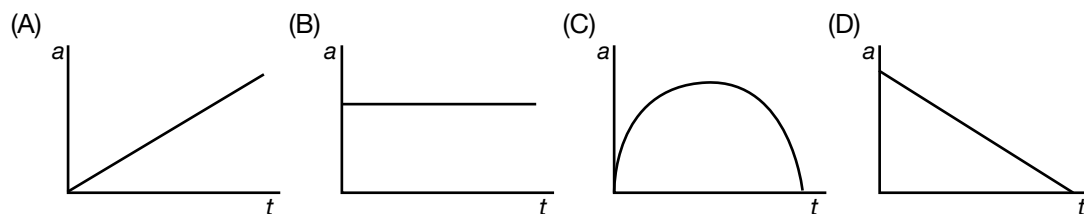
Which dotted line shows the path it will take?

- (A) A
- (B) B
- (C) C
- (D) D

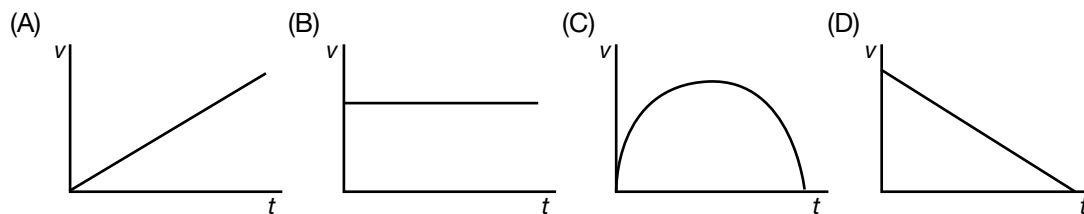


Extension: Justify your answer.

9.1.1.6 A ball is rolled at constant speed along a horizontal benchtop until it falls over the edge towards the floor. Which graph best shows the acceleration of the ball as it falls to the floor?



9.1.1.7 A ball is rolled at different speeds along a horizontal benchtop until it falls over the edge towards the floor. Which graph best shows the velocity of the ball as it falls to the floor?



9.1.1.8 Four balls are rolled at different speeds along a benchtop until they fall over the edge towards the floor. Which statement about these balls is correct?

- (A) All four balls will hit the floor at the same time.
- (B) The slowest ball will hit the floor first; the fastest will hit it last.
- (C) The fastest ball will hit the floor first; the slowest will hit it last.
- (D) All four balls will land in the same position at the same time.

9.1.1.9 Outline the characteristics of the motion of a projectile.

9.1.1.10 List Galileo's three findings regarding projectile motion.

9.1.1.11 The table shows the results of an experiment where a ball was rolled along a smooth, horizontal surface at 15 m s^{-1} and then over the edge of a 150 m drop. The ball left the surface and started to fall at time zero.

Demonstrate that these results are consistent with Galileo's analysis of projectile motion. Do working on your own paper.

Time (s)	Speed of ball (m s^{-1})
1	17.92
2	24.68
3	33.01
4	41.97

9.1.2 Describe and sketch the trajectory of projectile motion as parabolic in the absence of air resistance.

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9.1.3 Describe qualitatively the effect of air resistance on the trajectory of a projectile. © IBO 2007

Note that 9.1.2 and 9.1.3 are combined and questions carry 9.1.2 numbers.

9.1.2.1

- (a) Sketch the trajectory of a projectile fired from ground level and falling back to ground level in the absence of air resistance. List the characteristics of this flight.

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- (b) Sketch the trajectory of a projectile fired from ground level and falling back to ground level in the presence of air resistance. List the characteristics of this flight.

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- (c) Explain the difference in the two trajectories.

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9.1.2.2 Describe the effect of air resistance on the following aspects of the flight of a projectile. In each case indicate why this effect will occur.

(a) Its range.

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(b) Its time of flight.

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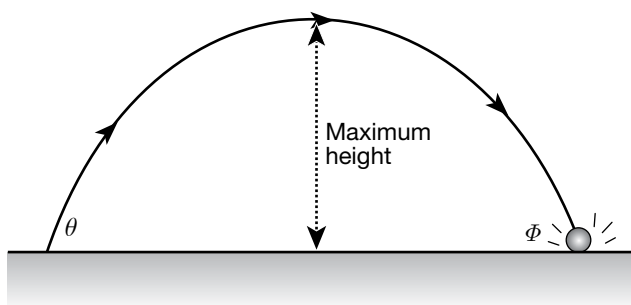
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(c) Its maximum height after being projected into the air.

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9.1.2.3 Consider a projectile which follows a path as shown in the diagram.



How will air resistance affect the relative sizes of the angle of launch (θ) compared to the angle at which it lands (ϕ)? Justify your answer.

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9.1.2.4 In order to hit its target, physics equations indicate that a projectile needs to be fired at its maximum speed at a launch angle of 37° . It is fired.

(a) Will it hit the target? Justify your answer.

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(b) If you said 'no' to answer (a), what needs to be done so that it does hit the target?

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9.1.2.5 The diagram shows the path of a small spherical object thrown outwards from the top of a 120.0 m high cliff on the planet Xenos. The images of the object were taken every 0.2 s.

- (a) Use the diagram to comment on the effect of air resistance on this object.

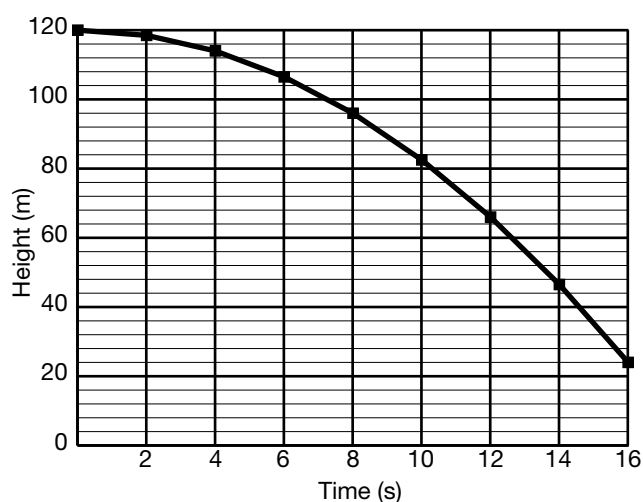
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- (b) Determine the value of the acceleration due to gravity on the planet Xenos.

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9.1.4 Solve problems on projectile motion. © IBO 2007

9.1.4.1 Four model rockets are launched with the velocity components shown in the table. Which rocket was launched at 30° to the horizontal?

Extension: What would be the time of flight of rocket (A)?

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Rocket	Horizontal component of velocity (m s^{-1})	Vertical component of velocity (m s^{-1})
(A)	20	50
(B)	30	40
(C)	40	20
(D)	50	30

9.1.4.2 A ball is hit into the air at 45 m s^{-1} 30° to the horizontal. What is its speed 2 s later?

- (A) 2.9 m s^{-1}
- (B) 19.6 m s^{-1}
- (C) 25.4 m s^{-1}
- (D) 39.1 m s^{-1}

Extension: Which two answers are more obviously incorrect than the third incorrect answer? Explain your reasoning.

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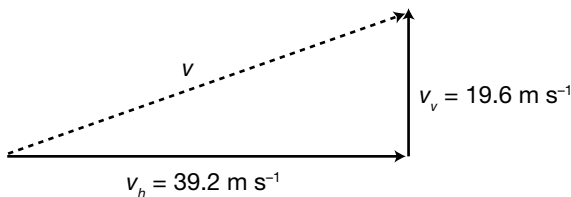
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9.1.4.3 The velocity of a projectile 2.0 s after its launch can be found from the following vector diagram. What was the launch velocity of the projectile?

- (A) 39.2 m s^{-1} at 45° to the horizontal.
- (B) 43.8 m s^{-1} at 30° to the horizontal.
- (C) 55.4 m s^{-1} at 45° to the horizontal.
- (D) 55.4 m s^{-1} at 30° to the horizontal.



Extension: Which two answers can be seen as being incorrect without doing any calculations? Explain why.

9.1.4.4 A student rolls two balls X and Y, X with mass m and Y with mass $2m$ across a benchtop so that they leave the edge at the same time and with the same speed.

Four students made statements about the flight of the two balls.

Jacinta: Y hits the ground before X.

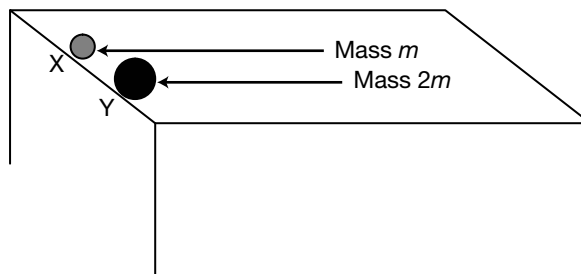
Chin: X and Y hit the ground at the same time.

Mario: X hits the ground twice as far away from the table compared to Y.

Pasqual: X hits the ground the same distance from the table as Y.

Whose statement about the two balls is correct?

- (A) Pasqual and Jacinta.
- (B) Pasqual and Chin.
- (C) Mario and Jacinta.
- (D) Mario and Chin.

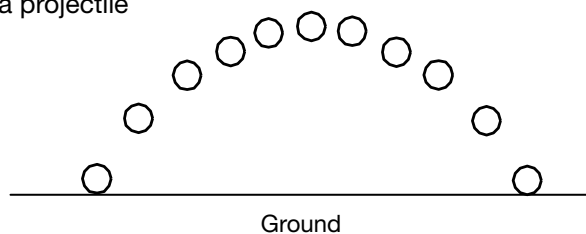


Extension: Justify your answer.

9.1.4.5 The diagram shows a stroboscopic photograph of a projectile which has a time of flight of 10.0 s.

What was its initial vertical speed?

- (A) 49 m s^{-1}
- (B) 98 m s^{-1}
- (C) 147 m s^{-1}
- (D) Additional information is required to determine this.



Extension: Calculate the frequency of the stroboscope used to produce this diagram.

9.1.4.6 A cannon was fired at an elevation of 40° . It was then loaded with an identical charge and ball and fired again at an elevation of 50° . Which statement about the two cannonballs is correct?

- (A) The first cannonball will have the longer range.
- (B) The first cannonball will have the shorter range.
- (C) The first cannonball will have a longer time of flight.
- (D) The first cannonball will have a shorter time of flight.

Extension: Compare the ranges of the two cannonballs.

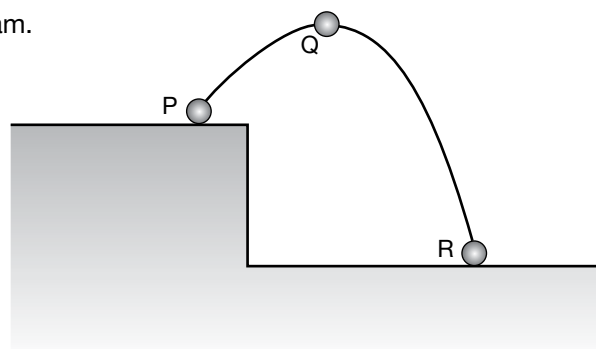
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9.1.4.7 A projectile follows the pathway shown in the diagram. Which statement about this projectile is correct?

- (A) The time of flight from P to R is twice the time from P to Q.
- (B) The acceleration of the projectile is independent of its launch velocity.
- (C) The vertical component of the velocity is the same at P, Q and R.
- (D) The horizontal component of the velocity is greatest at Q.



Extension: Compare the horizontal, vertical and overall velocities of the projectile at P and R.

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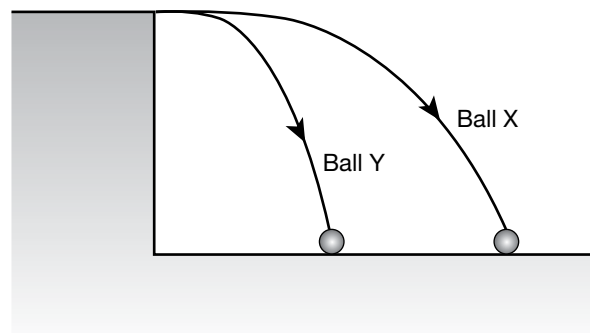
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9.1.4.8 Ball X is projected horizontally from the edge of a 1.2 m high table at 2.6 m s^{-1} . Ball Y is projected horizontally out from the edge of the table at 1.5 m s^{-1} .

Approximately how much further out from the edge of the table does ball X land?

- (A) 0.5 m
- (B) 0.7 m
- (C) 1.0 m
- (D) 1.25 m



Extension: With what velocity will X hit the floor?

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9.1.4.9 A projectile is fired horizontally at 150 m s^{-1} from the top of a 196 m high cliff. Calculate:

(a) Its time of flight.

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(b) Its range.

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(c) Its velocity on hitting the ground.

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9.1.4.10 A projectile has a time of flight of 7.5 s and a range of 1200 m . Calculate:

(a) Its horizontal velocity.

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(b) Its maximum height.

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(c) The velocity with which it is projected.

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9.1.4.11 A cannonball is fired at 80 m s^{-1} at an angle of 45° to the horizontal. Calculate the height at which the ball hits a vertical cliff 150 m away.

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9.1.4.12 Projectile problems 1: Object projected from a horizontal surface.

For each of the problems below, consider a projectile dropped vertically out of a moving object such as a plane, thrown horizontally out from the top of a cliff, or fired horizontally and landing on a surface as shown in the diagram. For each problem find any of these quantities which are not in the given data (not necessarily in the order given).

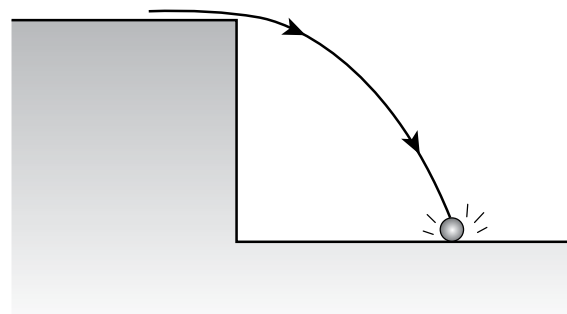
Answer all questions on your own paper.

Special considerations

Initial vertical velocity = 0

$\theta = 0^\circ$

- (a) The initial velocity of the projectile.
- (b) Its initial horizontal velocity.
- (c) Its initial vertical velocity.
- (d) Its range.
- (e) Its final horizontal velocity.
- (f) Its final vertical velocity.
- (g) Its final velocity.
- (h) The time taken to fall.
- (i) The height from which it was thrown/dropped.
- (j) Its velocity 3 seconds after dropping.
- (k) Its height 5 seconds after dropping.



1. A lifeboat is dropped from a plane moving at 140 m s^{-1} from a height of 1102.5 m .
2. A box of supplies is dropped from a helicopter moving horizontally at 80 m s^{-1} . The supplies hit the ground 9.0 s later.
3. A ball is thrown horizontally from the top of a building and lands in a bucket on the ground 50 m in front of the building 3.0 s later.
4. A rock is thrown horizontally out from the top of a 147 m cliff. It hits the ground 80 m from the base of the cliff.
5. A ball thrown horizontally out from the top of a cliff hits the ground 6 s later at 30° to the vertical, and moving at 67.9 m s^{-1} .
6. A cannonball is fired horizontally from the ramparts of a castle. It hits its target 150 m away after 7.5 s .
7. An arrow is fired horizontally at the centre of a target 50 m away. Unfortunately, the archer made no allowance for gravity, and the arrow hit 0.8 m below centre.
8. A cannon fires a ball at 150 m s^{-1} which hits its target 675 m away.
9. A lifeboat is dropped from a plane moving at 80 kph . It lands in the water 8 s later.
10. A projectile hits the centre of a target at an angle of 15° to the vertical 15 s after being dropped from a helicopter.
11. A car, travelling at 30 m s^{-1} , drives over the edge of a cliff and into the water 58.8 m below.
 - (a) Calculate the time it takes the car to hit the water.
 - (b) Calculate the distance from the cliff that the car hits the water.
 - (c) Calculate the speed of the car just as it hits the water.
12. A group of lemmings run over the edge of a 200 m cliff at 0.6 m s^{-1} .
 - (a) Calculate their time to fall to the bottom of the cliff.
 - (b) Calculate their velocity halfway down.
 - (c) Calculate the time their vertical speed will be 30.0 m s^{-1} .
 - (d) Calculate the speed at which they hit the ground.

9.1.4.13 Projectile problems 2: Object thrown upwards and landing at the same level.

Special considerations:

Total vertical displacement = 0.

Vertical velocity at top of flight = 0.

Time to rise = time to fall.

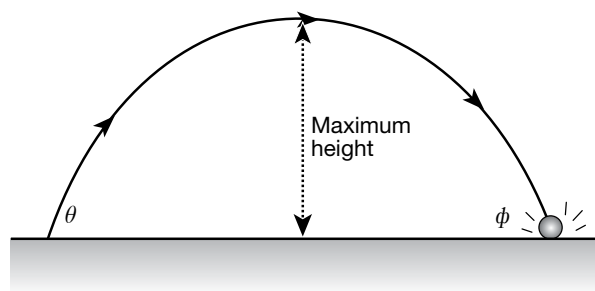
Time to rise = half time of flight.

Speed at launch = speed at land.

Angle θ = angle ϕ

Two halves of flight are symmetrical.

Maximum height occurs when vertical velocity = 0.



For each of the problems below, consider a projectile fired at an angle and landing on a surface at the same level as that from which it was fired, as shown in the diagram. For each problem find any of these quantities which are not in the given data (not necessarily in the order given). Answer all questions on your own paper.

- The initial velocity of the projectile.
 - Its initial horizontal velocity.
 - Its initial vertical velocity.
 - Its range.
 - its maximum height.
 - The time it takes to reach maximum height.
 - Its time of flight.
- Projectile is fired at 20 m s^{-1} at 30° to the horizontal.
 - Projectile is fired at 30 m s^{-1} and has a range of 79.5 m. It is in flight for 5.3 s.
 - Projectile is fired at 35.6 m s^{-1} at 55.8° to the horizontal and hits the ground 6 s later.
 - Projectile has a range of 318.2 m and rises to a maximum 60 m.
 - Projectile is fired at 50° to the horizontal and rises 2.0 km.
 - Projectile has a range of 2.5 km and rises for 30 s.
 - Projectile is fired at 200 m s^{-1} at 45° .
 - Projectile is fired at 40° to the horizontal at 150 m s^{-1} .
 - Projectile rises to a height of 81.6 m after being fired at 60° to the horizontal.
 - Projectile hits a target 1.2 km away, 30 s after firing at 74.8° .
 - Projectile rises to a maximum height of 127.5 m and has a range of 408.2 m.
 - Projectile rises to 0.75 km, having been fired at 286.9 m s^{-1} .
 - Projectile is fired at 400 m s^{-1} and rises for 20.4 s.
 - Projectile needs to be fired with minimum velocity and hit a target 3.0 km away 21 s after firing.
 - The vertical component of the velocity of a projectile is 147 m s^{-1} and its horizontal component of its velocity is 91.6 m s^{-1} .

9.1.4.14 Projectile problems 3: Object thrown upwards and landing at a different level.

Special considerations

Total vertical displacement = difference in height between the two levels.

If target lower, then vertical displacement is negative (assume upward direction positive).

If target higher, vertical displacement positive.

Vertical velocity at top of flight = 0.

Time to rise *does not* equal time to fall.

Time to rise *is not* half the time of flight.

Speed at launch *does not* equal speed at land.

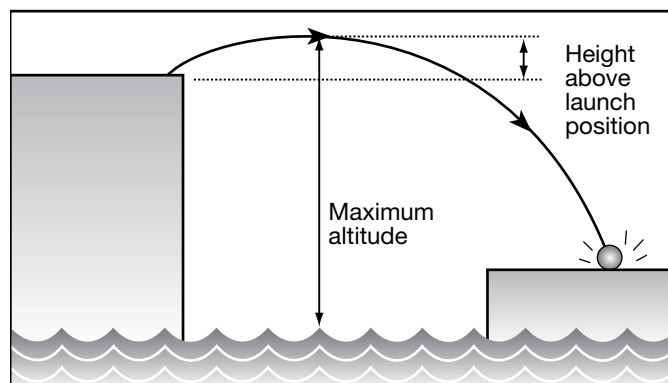
Angle of launch *does not* equal angle of landing.

Two halves of flight are *not* symmetrical.

Maximum height occurs when vertical velocity = 0.

For each problem below, consider a projectile fired at an angle and landing on a surface either below or higher than that from which it is fired, as shown in the diagram.

For each problem find any of these quantities which are not in the given data (not necessarily in the order given). Answer all questions on your own paper.



- (a) The initial velocity of the projectile.
- (b) Its initial horizontal velocity.
- (c) Its initial vertical velocity.
- (d) Its range.
- (e) Its maximum height above launch position.
- (f) The time it takes to reach maximum height.
- (g) Its time of flight.

1. A projectile is fired at 30° to the horizontal from the top of a cliff 200 m high. Its initial speed is 49 m s^{-1} .
2. A projectile is fired from the top of a 120 m high cliff at 25 m s^{-1} . It lands on the ground 6.4 s after firing.
3. A cannon is at the top of a 60 m high cliff firing at a castle on top of an adjacent cliff 110 m high. The cannon and castle are 200 m apart horizontally. The cannonballs hit 20 s after firing.
4. A cannonball is fired at 50 m s^{-1} from the top of a 200 m high cliff so that maximum range is achieved.
5. A rock is thrown at 15 m s^{-1} from the top of a 75 m high cliff. The rock lands at the bottom of the cliff 4.0 s later.
6. A projectile is thrown up from the top of a 60 m high cliff. It rises to a maximum height of 44.1 m above the cliff top. It hits the ground 76 m out from the base of the cliff.
7. A ball is thrown out from the edge of a 40 m high cliff with a velocity of 35.1 m s^{-1} at 30° to the horizontal.
8. A cannonball is fired at 40 m s^{-1} at 40° to the horizontal from the top of a 218.7 m cliff and hits a target 300 m from the base of the cliff.

- 
9. A projectile fired into the air from a 75 m high cliff hits the ground 500 m out from the base 10 s later.
10. A cannon fires from the top of a 150 m high cliff at a castle 300 m from the base of the cliff. The ball hits the castle 15 s later.
11. A cannonball is fired at 40 m s^{-1} at an angle of 35° to the horizontal. Calculate the height at which the ball hits a vertical cliff 50 m away.
12. A player kicked a football from 30 m in front of the goalposts. The ball just cleared the crossbar which was 3.0 m above the ground 2.0 s later. Calculate:
- (a) The angle at which the ball was kicked.
 - (b) The ball's initial speed.
13. A projectile is fired from the top of a cliff and reaches a height of 147 m above its launch point. It lands 980 m from the base of the cliff 20 s after launch. Calculate:
- (a) The height of the cliff.
 - (b) The velocity at which the projectile was launched.

9.2 Gravitational field, potential and energy. © IBO 2007

9.2.1 Define gravitational potential and gravitational potential energy. © IBO 2007

9.2.2 State and apply the expression for gravitational potential due to a point mass. © IBO 2007

9.2.3 State and apply the formula relating gravitational field strength to gravitational potential gradient.

© IBO 2007

Note that 9.2.1, 9.2.2 and 9.2.3 are combined and questions carry 9.2.1 numbers.

9.2.1.1 Define gravitational potential.

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9.2.1.2 Define gravitational potential energy.

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9.2.1.3 Explain why we take infinity as the position of zero gravitational potential energy.

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9.2.1.4 Account for the gravitational potential energy of a mass in a gravitational field having a negative value.

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9.2.1.5

(a) State the expression we use to calculate the gravitational potential energy (E_p) of a mass of mass m kg distance R from the centre of the Earth.

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(b) State the expression we use to find the gravitational potential of a mass (V) of mass m kg distance R from the centre of the Earth.

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(c) Combine these two equations to derive an equation which connects gravitational potential energy and gravitational potential.

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- (d) Using Newton's equation for finding the gravitational force on a mass in a gravitational field, derive an expression for the gravitational field strength, g , at a distance of R from the centre of the Earth.

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- (e) Using this expression, and the one from (c) above, derive an expression which connects gravitational potential and gravitational field strength.

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- (f) We have, in the past, used the equation $W = mgh$ to find the gravitational potential energy of a mass m distance h above the surface of the Earth. What is a more correct form of this equation?

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- (g) Explain why this equation (your answer to (f)) is better.

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- (h) Explain why the equations you found in (b) or (e) above are better to use than the equation $W = mgh$.

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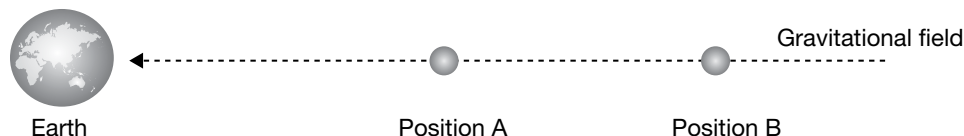
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- 9.2.1.6** Consider two points A and B distance Δx apart near Earth as shown in the diagram. The gravitational potential at point A is equal to V , and that at point B is $V + \Delta V$. The strength of the gravitational field strength in the region of A and B is g .



- (a) State two equations for the work done in moving from B to A, one in terms of the gravitational force acting, the other in terms of the gravitational potential.
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- (b) From these two equations write an expression for the strength of the gravitational field in the region of A and B.
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- (c) What assumption has been made in deriving the expression above?
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- (d) Use this expression to write a definition of gravitational field strength in terms of gravitational potential.
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9.2.4 Determine the potential due to one or more point masses. © IBO 2007

9.2.5 Describe and sketch the pattern of equipotential surfaces due to one and two point masses. © IBO 2007

9.2.6 State the relation between equipotential surfaces and gravitational field lines. © IBO 2007

Note that 9.2.4, 9.2.5 and 9.2.6 are combined and questions carry 9.2.4 numbers.

9.2.4.1 All gravitational potentials are negative. Explain what this means.

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9.2.4.2

- (a) Determine the gravitational potential energy of a 250 kg satellite at an altitude of 36 000 km above the surface of the Earth. The mass of the Earth is 6×10^{24} kg and its diameter is 12 560 km.
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- (b) Determine the gravitational potential at the position of this satellite.
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- (c) Given that both gravitational potential energy and gravitational potential are scalar quantities, explain why they are both negative.

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9.2.4.3 What is meant by an 'equipotential' surface?

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9.2.4.4

- (a) Sketch the equipotential lines (dotted lines) around a point mass. Also show the gravitational field lines (as solid lines).

- (b) Sketch the equipotential lines (dotted lines) around two point masses which are near each other. Also show gravitational field lines (as solid lines).

9.2.4.5 State the relationship between equipotential surfaces and gravitational field lines.

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9.2.7 Explain the concept of escape speed from a planet. © IBO 2007

9.2.8 Derive an expression for the escape speed of an object from the surface of a planet. © IBO 2007

Note that 9.2.7 and 9.2.8 are combined and questions carry 9.2.7 numbers.

9.2.7.1 Explain what we mean by escape speed.

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9.2.7.2 The escape speed from Earth is about $11\,200\text{ m s}^{-1}$. Does this mean that a spaceship must be moving at this speed in order to escape the Earth's gravitational field? Explain your answer.

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9.2.7.3 Derive an expression for the escape speed of an object from the surface of a planet.

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9.2.7.4 The escape velocity for Mars is about 5.0 kps while that for Earth is 11.2 kps. What two factors could account for this difference? Explain your answer.

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9.2.7.5 The Moon has a mass of $7.35 \times 10^{22}\text{ kg}$ and a diameter of 3467 km. Determine its escape velocity.

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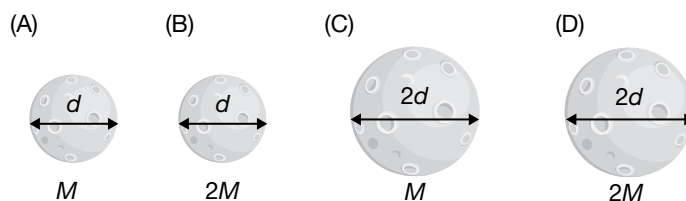
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9.2.7.6 The diagrams show the sizes and masses of four planets, A, B, C and D.

For which planet would the escape velocity be greatest?

- (A) A
- (B) B
- (C) C
- (D) D



Extension: For which two planets is the escape velocity the same?

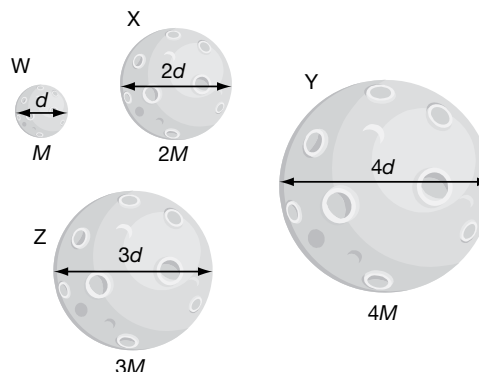
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9.2.7.7 The escape velocity for planet X is greater than the escape velocity for planet Y. Which statement about planets X and Y is correct?

- (A) If the mass of X < the mass of Y, then the diameter of X must be > the diameter of Y.
- (B) If the mass of X > the mass of Y, then the diameter of X must be > the diameter of Y.
- (C) If the mass of X < the mass of Y, then the diameter of X must be < the diameter of Y.
- (D) If the mass of X > the mass of Y, then the diameter of X must be < the diameter of Y.

9.2.7.8 The diagrams show the sizes and masses of four planets, W, X, Y and Z.

Which statement about the escape velocities of these planets is correct?



- (A) Escape velocity is largest for planet Z.
- (B) Escape velocity for planet Z > planet Y > planet Z = planet X.
- (C) Escape velocity is largest for planet W.
- (D) Escape velocity is the same for each planet.

9.2.7.9 Which of the following factors does *not* affect the magnitude of escape velocity?

- (A) The mass of the rocket.
- (B) The mass of the planet.
- (C) The diameter of the planet.
- (D) The universal gravitational constant.

9.2.7.10 The escape velocity of a particular planet is 2500 m s^{-1} . Which of the following statements is correct?

- (A) A rocket needs to accelerate to 2500 m s^{-1} before it can break away from the planet's gravitational field.
- (B) A rocket moving more slowly than 2500 m s^{-1} can only go into orbit around the planet.
- (C) A projectile without its own rockets would have to be fired at 2500 m s^{-1} from the surface of the planet if it is to escape the planet's gravitational field.
- (D) A rocket moving at 1000 m s^{-1} would be unable to break away from the planet's gravitational field.

Extension: Explain your answer.

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9.2.7.11 Mercury has a mass of $3.58 \times 10^{23} \text{ kg}$ and a diameter of 4880 km. Venus has a mass of $4.92 \times 10^{24} \text{ kg}$ and a diameter of 12 104 km. Without calculating values, predict which has the greater escape velocity and explain your reasoning.

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9.2.9 Solve problems involving gravitational potential energy and gravitational potential. © IBO 2007

9.2.9.1 A satellite of mass 500 kg is raised from an orbital radius of 7.3×10^6 m to a geostationary orbit of orbital radius 4.2×10^7 m. Taking the mass of the Earth as 6×10^{24} kg, what is the change in its gravitational potential energy?

- (A) +3641.5 J
- (B) -3641.5 J
- (C) $+2.26 \times 10^{10}$ J
- (D) -2.26×10^{10} J

Extension: Explain the '+' or the '-' of your choice.

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9.2.9.2 The gravitational potential energy between two objects is E . The distance between the objects is halved. How much work was done in moving the objects closer together?

- (A) $0.5E$
- (B) $1.0E$
- (C) $2.0E$
- (D) $4.0E$

Extension: Explain your answer.

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9.2.9.3 What is the relationship between the work done on an object and its gravitational potential energy?

- (A) The work done on the object equals its gravitational potential energy.
- (B) The work done on the object equals the change in its gravitational potential energy.
- (C) The work done on the object equals the increase in its gravitational potential energy.
- (D) The work done on the object equals the decrease in its gravitational potential energy.

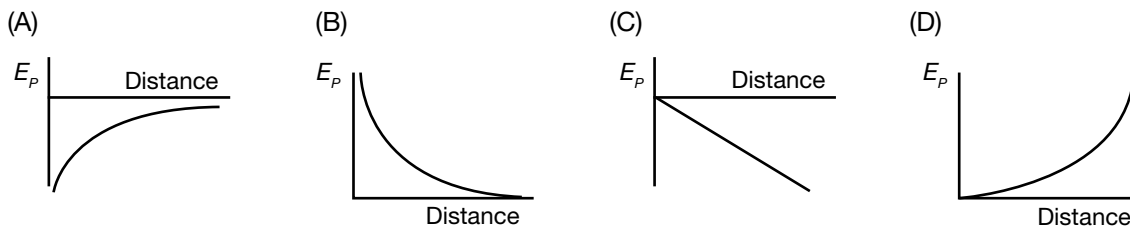
Extension: Identify the source of the work done when the orbit of a satellite decays.

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9.2.9.4 When will the gravitational potential energy of an object be zero?

- (A) When it is at infinity.
- (B) When it is on the surface of a planet.
- (C) When it is in outer space.
- (D) When its acceleration is 9.8 m s^{-2} .

9.2.9.5 Which of the graphs best shows the relationship between the gravitational potential energy of an object and its distance from the centre of the Earth?



Extension: Explain your answer.

9.2.9.6 A satellite is moved to a higher altitude orbit. Which statement about this satellite is correct?

- (A) Work is done by the satellite engines and its E_p increases.
- (B) Work is done by the satellite engines and its E_p decreases.
- (C) Work is done by gravity and its E_p increases.
- (D) Work is done by gravity and its E_p decreases.

9.2.9.7 What is the gravitational potential energy of a 200 kg satellite 300 km above the surface of the Earth? The diameter of the Earth is 12 756 km.

- (A) $-1.79 \times 10^3 \text{ J}$
- (B) $-8.59 \times 10^9 \text{ J}$
- (C) $-1.19 \times 10^{10} \text{ J}$
- (D) $-2.00 \times 10^{13} \text{ J}$

Extension: Would the E_p of this satellite be greater or less if it was at an altitude of 600 km? Explain.

9.2.9.8 A rocket is in orbit distance R from the centre of the Earth. At this height it has gravitational potential energy equal to E joules. The rocket is then boosted to a higher orbit, orbital radius $3R$. How has its gravitational potential energy changed?

- (A) Increased by one third.
- (B) Decreased by one third.
- (C) Increased by two thirds.
- (D) Decreased by two thirds.

Extension: Justify your answer.

9.2.9.9 A rocket is in orbit distance R from the centre of the Earth. At this height it has gravitational potential energy (E_p) equal to E joules. The rocket is then boosted to an orbit where its E_p is $3E$. Which statement about this rocket is correct?

- (A) It is in a higher orbit and $2E$ work has been done on it by its engines.
- (B) It is in a higher orbit and $2E$ work has been done on it by gravity.
- (C) It is in a lower orbit and $2E$ work has been done on it by its engines.
- (D) It is in a lower orbit and $2E$ work has been done on it by gravity.

Extension: Justify your answer.

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9.2.9.10 What is the gravitational potential energy of a 200 kg satellite on the surface of the Earth? The diameter of the Earth is 12 756 km.

- (A) -1.96×10^3 J
- (B) -1.25×10^{10} J
- (C) -8.49×10^{12} J
- (D) -1.25×10^{13} J

Extension: Would the E_p of this satellite be greater or less if the satellite had a mass of 400 kg? Explain.

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9.2.9.11 What is the gravitational potential energy of a 200 kg satellite 3000 km above the surface of the Earth? The diameter of the Earth is 12 756 km.

- (A) -9.06×10^2 J
- (B) -8.50×10^9 J
- (C) -1.25×10^{10} J
- (D) -8.50×10^{12} J

Extension: Would the E_p of this satellite be greater or less if it was at an altitude of 3000 km above the Moon? Explain.

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9.2.9.12 What work needs to be done against gravity to lift a 200 kg satellite to an altitude of 3000 m?

- (A) $+1.05 \times 10^3$ J
- (B) -4.00×10^9 J
- (C) $+4.00 \times 10^9$ J
- (D) $+8.48 \times 10^{12}$ J

Extension: Would the extra work be greater for a satellite of mass 400 kg? Explain.

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9.2.9.13 Calculate the gravitational potential energy of a 2000 kg satellite which orbits the Earth at an altitude of 35 000 km. The radius of Earth is 6378 km.

9.2.9.14 A satellite of mass 500 kg is boosted from an orbit of altitude 10 000 km to one of altitude 20 000 km. Given the diameter of Earth as 12 756 km, its mass as 5.97×10^{24} kg, calculate the change in the gravitational potential energy of the satellite.

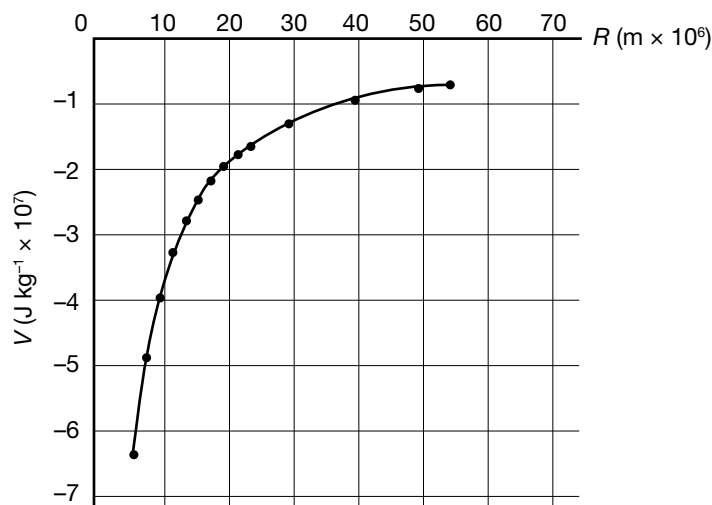
9.2.9.15 Explain the relationship between the work done on an object which changes its position in a gravitational field and its gravitational potential energy.

9.2.9.16 The change in height of the water in a dam is exactly 150 m.

(a) What is the gravitational potential of the water at the top of the dam compared to the generators at the base of the dam?

(b) If water flows through the generators at the rate of 230 m^3 every second, how much electrical energy will be produced (assume 100% efficiency)?

9.2.9.17 The graph shows how the gravitational potential varies with distance from the Earth's centre.



(a) Estimate the increase in the gravitational potential energy of a 400 kg satellite launched from the surface to an altitude of 34 000 km.

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(b) Estimate the energy required to send this satellite from the Earth's surface to infinity.

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(c) State the units for the gradient of the graph.

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(d) Determine the gradient of the graph at the Earth's surface.

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(e) What does this value represent?

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[illegible]

9.3 Electric field, potential and energy. © IBO 2007

9.3.1 Define electric potential and electric potential energy. © IBO 2007

9.3.1.1

(a) Define electric potential.

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(b) State two different units for electric potential.

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9.3.1.2 Compare the potential associated with equal positive and negative point charges.

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9.3.1.3

(a) Define electric potential energy.

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(b) Explain why the definition includes the phrase 'negative of the work done'.

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9.3.2 State and apply the expression for electric potential due to a point charge. © IBO 2007

9.3.2.1 State the expression for the electric potential at distance r from a point charge.

9.3.2.2

(a) Determine how much work is done by the electric field when a point charge of $+6.0 \mu\text{C}$ is moved from infinity to a point which is 25 cm from a charge of $4.0 \times 10^{-8} \text{ C}$.

(b) Predict how much work would be done by the electric field when a point charge of $-6.0 \mu\text{C}$ is moved from infinity to a point which is 25 cm from a charge of $4.0 \times 10^{-8} \text{ C}$.

(c) Explain the difference in your answers to (a) and (b).

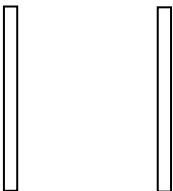
9.3.2.3 Determine the potential at a distance of 50 cm from a charge of 9.0 pC.

9.3.2.4 Charge X, $4 \times 10^{-8} \text{ C}$, is 25 cm from charge Y, $-5.0 \times 10^{-8} \text{ C}$. X is moved to a new position, 50 cm from charge Y. Determine its change in potential.

9.3.3 State and apply the formula relating electric field strength to electric potential gradient. © IBO 2007

9.3.3.1 Consider the situations described in the table below. For each situation:

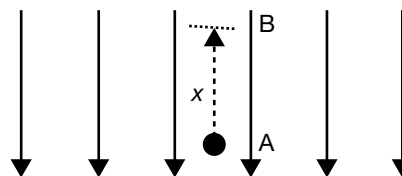
- Draw the electric field lines around each.
- Draw a graph to represent how the potential near each changes.
- Draw a graph to show how the electric field intensity changes near each.

Electric field lines around each	Potential near each	Field intensity near each
(a) Between parallel plates. 		
(b) Around point positive charge. 		
(c) Around point negative charge. 		
(d) Between unlike charges. 		
(e) Between like charges. 		

9.3.3.2 State the formula relating electric field strength to electric potential gradient.

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9.3.3.3 Imagine that a positive charge is moved from point A to point B, distance x metres, in an electric field as shown in the diagram.



(a) Write an expression for the work done on the charge in moving from A to B in terms of the applied force and the distance it moves.

(b) Write an expression for the work done on the charge in terms of the charge and the potential through which it moves (V).

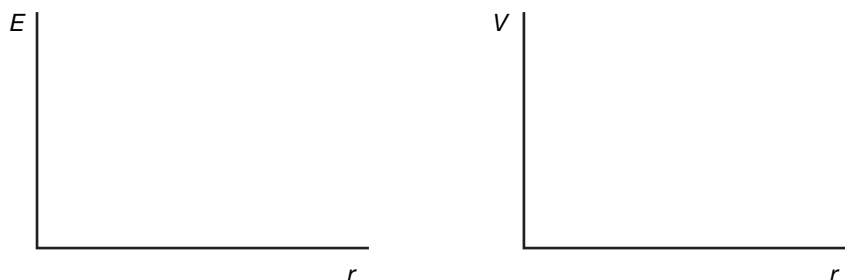
(c) Write an expression for the force applied to the charge to do this work in terms of the charge and the electric field strength.

(d) Combine your equations to derive an expression for the strength of the electric field in terms of the potential and distance through which the charge moves.

(e) Use this expression to define potential gradient.

(f) State the units used to measure potential gradient.

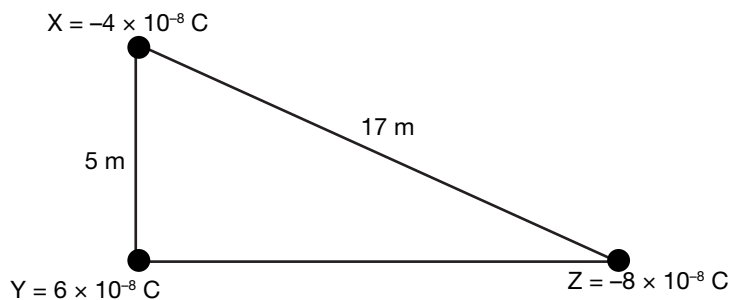
9.3.3.4 Consider a positively charged sphere of radius r metres. Construct graphs to show how the electric field and electric potential due to the charge on this sphere changes from the centre of the sphere to a finite distance away from the sphere.



9.3.4 Determine the potential due to one or more point charges. © IBO 2007

9.3.4.1 Calculate the electric potential 20 cm from a point charge of 3.0×10^{-10} C.

9.3.4.2 The diagram shows three point charges, X, Y and Z, at the vertices of a right-angled triangle.



(a) Calculate the electric potential at the position of charge Z due to the other two charges.

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(b) Calculate the electric potential at Y due to the other charges.

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(c) How would your answer to (b) change if the charge at Y was $-6 \times 10^{-8} \text{ C}$?

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9.3.5 Describe and sketch the pattern of equipotential surfaces due to one and two point charges. © IBO 2007

9.3.5.1 Draw a diagram to show the pattern of equipotential lines around the following.

(a) A point positive charge.

(b) A point negative charge.



9.3.5.2 Draw a diagram to show the pattern of equipotential lines around the following.

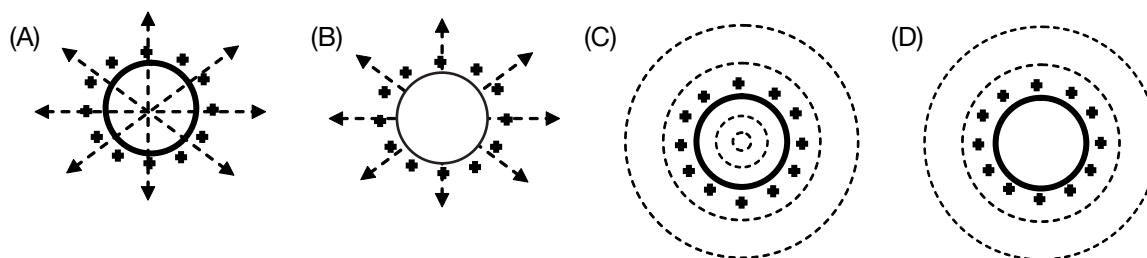
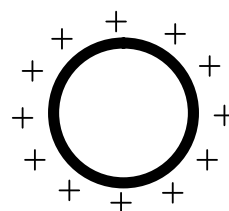
(a) Two like charges near each other.

(b) Two unlike charges near each other.

9.3.5.3 Draw a diagram to show the pattern of equipotential lines between charged, parallel plates.

- 9.3.5.4** Which of the following statements is true?
- (A) Work is done whenever a charge is moved along an equipotential.
 - (B) No work is required to move a charge along an equipotential.
 - (C) Equipotential lines are parallel to field lines.
 - (D) Equipotential lines are at various angles to field lines depending on their position relative to the charge.
- 9.3.5.5** Which of the following statements is true?
- (A) An equipotential is a region in space where the potential of a charge has a constant value.
 - (B) An equipotential is a region around a charge where the potential of a charge varies uniformly.
 - (C) An equipotential is a region around a charge where electric field changes uniformly.
 - (D) An equipotential is a region in space where no work needs to be done.
- 9.3.5.6** Which of the following statements is true?
- (A) Equipotential lines are always circular.
 - (B) Equipotential lines are always evenly spaced.
 - (C) Equipotential lines are always parallel to field lines.
 - (D) Equipotential lines are always perpendicular to field lines.

- 9.3.5.7** Consider the hollow, charged sphere shown.
Which diagram (A, B, C or D) correctly shows the equipotential lines (dashed lines in diagrams) associated with this sphere?



Extension: Explain your answer.

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9.3.6 State the relation between equipotential surfaces and electric field lines. © IBO 2007

9.3.6.1 State the relation between equipotential surfaces and electric field lines.

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9.3.6.2 Explain the difference between equipotential lines and equipotential surfaces.

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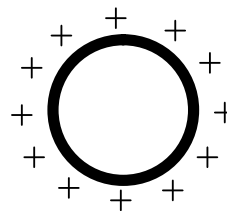
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9.3.6.3 Consider a hollow, charged sphere as shown in the diagram.

(a) State the nature of the electric field inside the sphere.

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(b) State the nature of the electric field outside the sphere.

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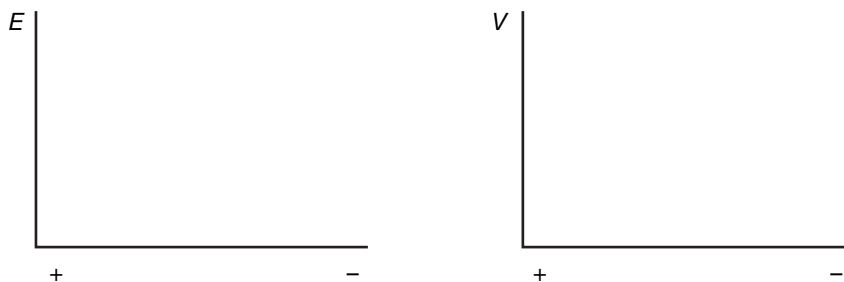
(c) State the nature of the electric potential inside the sphere.

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(d) State the nature of the electric potential outside the sphere.

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9.3.6.4 Construct graphs to show how the electric field and the electric potential vary between charged, parallel plates. (Take the origin of your graph as near the positive plate.)



9.3.7 Solve problems involving electric potential energy and electric potential. © IBO 2007

9.3.7.1 A positive point charge is placed at point X midway between two identical positive charges. Which statement regarding the electric field and the electric potential at point X is correct?

- (A) Both the field and the potential at X are zero.
- (B) Both the field and the potential have non-zero values.
- (C) The field is zero, but the potential has a value.
- (D) The field has value, but the potential is zero.

Use the following information to answer the next THREE questions.

The diagram shows two equipotential lines 4.0 cm apart between two charged, parallel plates. The plates are 20 cm apart.



9.3.7.2 What is the strength of the electric field between the plates?

- (A) 150 V m^{-1}
- (B) 225 V m^{-1}
- (C) 750 V m^{-1}
- (D) Unable to be determined with this data.

9.3.7.3 What is the potential difference between the plates?

- (A) 150 V
- (B) 600 V
- (C) 900 V
- (D) Unable to be determined with this data.

9.3.7.4 How much work would need to be done to move an electron from the 45 V line to the 15 V line?

- (A) $6.4 \times 10^{-19} \text{ J}$
- (B) $4.8 \times 10^{-18} \text{ J}$
- (C) $2.4 \times 10^{-17} \text{ J}$
- (D) $1.2 \times 10^{-16} \text{ J}$

9.3.7.5

(a) Determine the work done by an electric field in moving a point charge of $2 \times 10^{-8} \text{ C}$ from infinity to a point which is 4 mm from another point charge of $4 \times 10^{-8} \text{ C}$.

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(b) What would do this work? Explain your answer.

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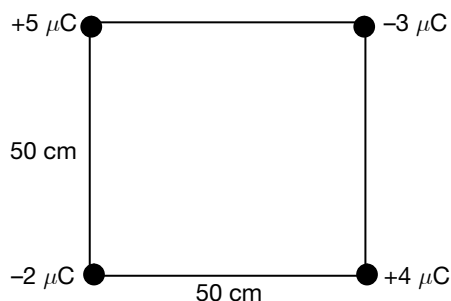
(c) What would do the work if either of the charges was negative?

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- 9.3.7.6** Two parallel electrically charged plates have a potential difference of 250 V and an electric field of $5.0 \times 10^5 \text{ V m}^{-1}$ between them. Determine how far apart they are.

- 9.3.7.7** An electron is accelerated through a cathode ray tube television set by a potential of 3500 V. Calculate the kinetic energy of the electron, in joules and electron volts, just before it hits the screen.

- 9.3.7.8** Four point charges are placed at the corners of a 50 cm square as shown in the diagram. Determine the potential at the centre of the square.

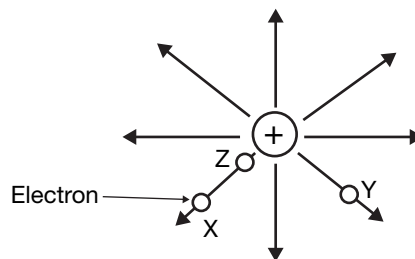


- 9.3.7.9** Two positively charged point charges are tied together by a light thread 5.0 cm long. Charge X has a mass of 4 g and carries $6.0 \mu\text{C}$ of charge. Charge Y has a mass of 12 g and a charge of $9.0 \mu\text{C}$.

(a) Determine the electric potential energy of the charges in this situation.

(b) The thread connecting the charges is cut. What will be the speed of X just after this cut?

- 9.3.7.10** An electron is at point X in an electric field near a point positive charge as shown in the diagram. Points Y and Z are other points in the field. Y is the same distance from the charge as X, but Z is much closer to the charge. As the electron moves from X to Z, the field does 4.0×10^{-18} J of work on it.



- (a) Calculate the potential difference between X and Z.

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- (b) Determine the potential difference between Y and Z.

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- (c) Determine the potential difference between X and Y.

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- 9.3.7.11** During a storm a lightning strike transferred 40 C of charge from a cloud to the ground through a potential difference of 1.5×10^9 V.

- (a) Determine the energy carried by the lightning strike.

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- (b) If this energy was input to a 5 tonne truck, what speed would it reach?

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- (c) Determine the mass of water at 20°C this amount of energy would boil.

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9.3.7.12 Determine the electric potential midway between two point charges X and Y 20 cm apart. X is $-3.6 \times 10^{-8} \text{ C}$, Y is $+5.0 \times 10^{-8} \text{ C}$.

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9.3.7.13 Three identical charges, each $-2.5 \times 10^{-9} \text{ C}$ are at the corners of a 60 cm equilateral triangle. Determine the electric potential at each corner.

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9.4 Orbital motion. © IBO 2007

9.4.1 State that gravitation provides the centripetal force for circular orbital motion. © IBO 2007

9.4.5 Discuss the concept of ‘weightlessness’ in orbital motion, in free fall and in deep space. © IBO 2007

Note that 9.4.1 and 9.4.5 are combined and questions carry 9.4.1 numbers.

9.4.1.1 Define a centripetal force.

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9.4.1.2 Give three examples of centripetal forces.

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9.4.1.3 List the forces acting on a satellite in stable orbit around the Earth.

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9.4.1.4

(a) When will an object be weightless?

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(b) An astronaut in orbit feels weightless, but he has centripetal force acting on him. Explain this.

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9.4.2 Derive Kepler’s third law. © IBO 2007

9.4.2.1 State Kepler’s third law.

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9.4.2.2 Derive Kepler’s third law equation.

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9.4.2.3

- (a) Given the mass of the Sun as 1.99×10^{30} kg, calculate the value of the Kepler constant for the Solar System.

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- (b) Given the mass of the Earth as 6×10^{24} kg, calculate the value of the Kepler constant for the Earth-Moon system.

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9.4.3 Derive expressions for the kinetic energy, potential energy and total energy of an orbiting satellite. © IBO 2007

Note that to avoid confusion between gravitational potential and gravitational potential energy, the symbols V and E_p have been used for these quantities respectively.

9.4.3.1 Write the equations for the following.

- (a) The gravitational potential (V) distance r from Earth’s centre.

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- (b) Newton’s equation for the gravitational force (F_g) between the Earth and mass m distance r from Earth’s centre.

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- (c) The centripetal force (F_c) acting on a satellite, mass m kg, in orbit r metres from the Earth’s centre with an orbital velocity of v m s⁻¹.

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- (d) The gravitational field strength (g_o) at the surface of the Earth.

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Using these equations derive an expression for the following.

- (e) The gravitational potential energy (E_p) of an object of mass m at r metres above the centre of the Earth in terms of the gravitational field strength at the surface of the Earth, the Earth's radius and the satellite's orbital radius.

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- (f) The kinetic energy (E_k) of an object of mass m moving with velocity $v \text{ m s}^{-1}$ a distance of r metres from Earth's centre in terms of the gravitational field strength at the surface of the Earth, the Earth's radius and the satellite's orbital radius.

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- (g) Compare your answers to (e) and (f) and comment on the relative values of the E_p and E_k of an orbiting satellite.

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- (h) The total energy (E_T) of an object of mass m , velocity v , in orbit r metres from Earth's centre.

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- (i) The difference in potential between the surface of the Earth and a point distance R from the surface.

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- (j) The difference in gravitational potential energy between the surface of the Earth and a point distance R from the surface.

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- (k) The work needed to lift a satellite of mass m from the surface of the Earth and a point distance R from the surface.

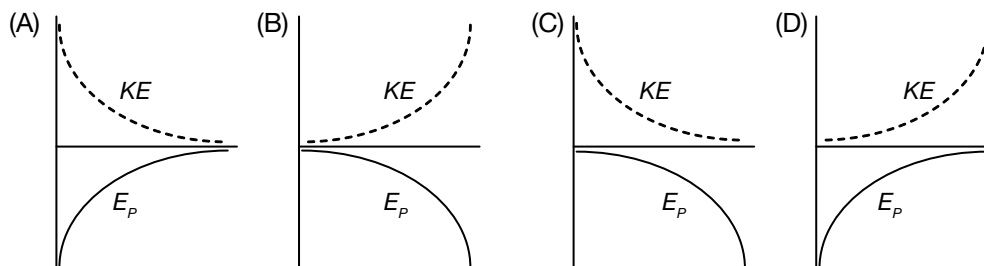
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9.4.4 Sketch graphs showing the variation with orbital radius of the kinetic energy, gravitational potential energy and total energy of a satellite. © IBO 2007

9.4.4.1 A projectile is fired from a cannon vertically into the air. It rises (without burning up) until it escapes from the Earth's gravitational field. Which graph shows how its gravitational potential energy (E_p) and kinetic energy (KE) change during its flight?



Extension: Justify your answer.

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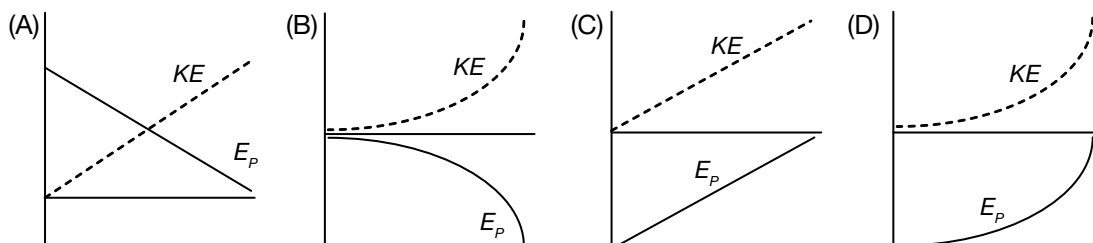
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9.4.4.2 A rocket takes off from the launch pad and rises under constant thrust until it escapes the Earth's gravitational field. Which graph best shows how its gravitational potential energy (E_p) and kinetic energy (KE) change during its flight?



Extension: Justify your answer.

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9.4.4.3 Construct graphs to show the relationship between the following.

(a) The orbital radius of a satellite and its kinetic energy. Justify your answer.

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(b) The orbital radius of a satellite and its gravitational potential energy. Justify your answer.

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(c) The orbital radius of a satellite and its total energy. Justify your answer.

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9.4.4.4 Construct three graphs on the same set of axes to show the relationship between the three separate graphs you drew in Question 9.4.4.3. Make sure you label each graph.



9.4.6 Solve problems involving orbital motion. © IBO 2007

9.4.6.1 Much more work needs to be done to put a 200 kg satellite into orbit at an altitude of 3000 m than is required to lift an identical object to the same altitude. Which choice best explains this?

- (A) Extra energy is needed to overcome air resistance.
- (B) The satellite also needs to be given orbital velocity.
- (C) To go into orbit the centripetal force needs to be overcome as well as the gravitational force.
- (D) Orbital potential energy is measured relative to the Earth's centre not the surface.

9.4.6.2 What is the centripetal force acting on a satellite of mass 200 kg orbiting at an altitude of 1000 km above planet X? The orbital speed of the satellite is 18 000 kph and planet X has a diameter of 8000 km.

- (A) 556 N
- (B) 720 N
- (C) 1.0×10^3 N
- (D) 1.3×10^4 N

Extension: How would the force change if the mass of X was doubled and all other variables were the same?

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9.4.6.3 An astronaut is in a 5000 kg spaceship which is orbiting planet Z at an altitude of 36 000 km. The acceleration due to gravity at that altitude is 4.0 m s^{-2} . How fast is the spaceship moving?

- (A) 0.01 m s^{-1}
- (B) $9.6 \times 10^{-5} \text{ m s}^{-1}$
- (C) $3.0 \times 10^{-6} \text{ m s}^{-1}$
- (D) Unable to be calculated without additional data.

Extension: If your answer was (D), what additional data do you think you need?

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9.4.6.4 Mercury has a mass of 3.58×10^{23} kg. Pluto has a mass of 1.27×10^{22} kg. What is the Kepler's law ratio of r^3/T^2 for Mercury compared to Pluto?

- (A) 1:1
- (B) About 3:1
- (C) About 27:1
- (D) Need period data to determine this ratio.

Extension: Would the ratio r^3/T^2 be the same for our Moon? Explain.

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9.4.6.5 Planet P has a mass of 4×10^{24} kg and a diameter of 10 000 km. A satellite orbits planet P at an altitude of 2000 km. What is the period of the satellite?

- (A) 1.98 hours.
- (B) 1.61 days.
- (C) 1.98 days.
- (D) 1.61 years.

Extension: Would the period be doubled if the altitude of the satellite was 4000 km? Explain.

9.4.6.6 Planet Q has a mass of 6×10^{24} kg and a diameter of 12 000 km. A satellite orbits planet Q in 90 minutes. What is the orbital altitude of the satellite?

- (A) 6.61×10^6 km
- (B) 6.66×10^6 km
- (C) 2.96×10^{17} m
- (D) 2.96×10^{20} km

Extension: How does orbital altitude differ from orbital radius?

9.4.6.7 The table gives information about two of the moons orbiting planet R.

What is the orbital period of moon Y?

- (A) 1.4 days.
- (B) 4.0 days.
- (C) 16 days.
- (D) 32 days.

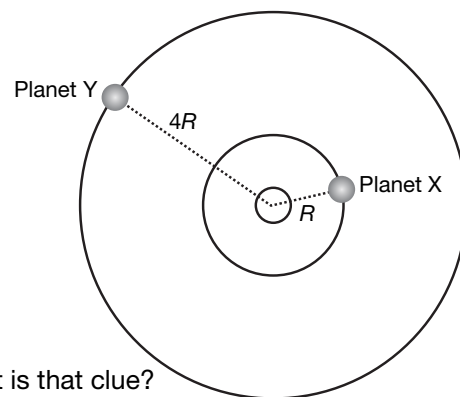
Moon	Radius of orbit (km)	Orbital period (days)
X	100 000	2.0
Y	400 000	T

Extension: Is the altitude of moon Y four times that of moon X? Explain.

9.4.6.8 Two planets, X and Y orbit the same star as shown. Planet X completes one orbit around the star in time T . The radii of the orbits are in the ratio 1:4.

How many orbits does planet Y make in time T ?

- (A) 1/8
- (B) 1/4
- (C) 1/2
- (D) 8



Extension: The choices give a clue to the correct answer. What is that clue?

9.4.6.9 Kepler's law of periods, summarised in the equation $T^2 = kR^3$, shows the relationship between the orbital period and radius of a planet orbiting a star. Which of the following would result in a change in the value of the constant, k ?

- (A) A planet of different mass orbiting the same star.
- (B) A planet of greater orbital radius.
- (C) A planet of greater orbital period.
- (D) An identical planet orbiting a different star.

9.4.6.10 Which statement correctly describes the forces acting on a satellite in a stable orbit?

- (A) No forces act on the satellite.
- (B) The net force on the satellite is zero.
- (C) The net force on the satellite is the gravitational force.
- (D) Two forces act, the gravitational force and the force causing forward motion.

Extension: Explain the difference between answers (A) and (B).

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9.4.6.11 An astronaut in an orbiting satellite appears 'weightless'. What force is acting on her?

- (A) No forces act on her.
- (B) Gravitational force only.
- (C) Gravitational force and air resistance only.
- (D) Gravitational force and the force of inertia only.

Extension: Why is the word 'weightless' in inverted commas?

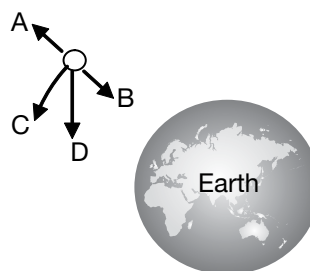
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9.4.6.12 Which arrow correctly shows the net force acting on a satellite in orbit?

- (A) A
- (B) B
- (C) C
- (D) D



9.4.6.13 Which of the following must be true if a satellite is in a stable orbit around Earth?

- (A) The period of the Earth's rotation must equal the period of the satellite.
- (B) The centripetal force acting on the satellite will be the gravitational force.
- (C) The net force acting on the satellite must be zero.
- (D) The satellite must be outside the Earth's gravitational field of influence.

Extension: One of the incorrect choices would be correct in special circumstances. Which one, and why?

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- 9.4.6.14** A satellite is in a stable orbit around Earth. What would happen to this satellite if gravity was suddenly 'switched off'?
- (A) It would move away from the Earth in the direction of its tangential motion at the time gravity was switched off.
 - (B) It would continue to orbit until an unbalanced force acted on it.
 - (C) It would spiral into Earth as the atmosphere causes orbital decay.
 - (D) It would move directly away from the Earth on a radial path.

Extension: Name and state the principle in physics that applies to this question.

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- 9.4.6.15** An astronaut is in a 2500 kg spaceship which is orbiting planet Z at an altitude of 36 000 km. The acceleration due to gravity at that altitude is 4.0 m s^{-2} . How fast is the spaceship moving?
- (A) 0.01 m s^{-1}
 - (B) $9.6 \times 10^{-5} \text{ m s}^{-1}$
 - (C) $3.0 \times 10^{-6} \text{ m s}^{-1}$
 - (D) Unable to be calculated without additional data.

Extension: If your answer was (D), what additional data do you think you need?

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- 9.4.6.16** Which of the following does *not* affect the orbital velocity of a satellite?
- (A) Its altitude.
 - (B) Its mass.
 - (C) The mass of the planet it orbits.
 - (D) The gravitational force of the planet.

Extension: In what way does gravitational force affect orbital velocity?

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- 9.4.6.17** Jupiter has a mass of $1.9 \times 10^{27} \text{ kg}$ and a diameter of 142 984 km. Saturn has a mass of $5.7 \times 10^{26} \text{ kg}$ and a diameter of 120 000 km. Which statement about the velocity of a satellite orbiting each planet at the same altitude is correct?
- (A) The velocity of the satellite orbiting Jupiter will be greater than that of the satellite orbiting Saturn.
 - (B) The velocity of the satellite orbiting Jupiter will be less than that of the satellite orbiting Saturn.
 - (C) The velocity of the satellite orbiting Jupiter will be equal to that of the satellite orbiting Saturn.
 - (D) Additional information is needed before this can be determined.

Extension: Account for the correctness or incorrectness of choice (C).

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9.4.6.18 Three moons around planet P have masses M , $4M$ and $16M$. They all have the same orbital radius. What is the ratio of their orbital speeds?

- (A) 1:1:1
- (B) 1:2:4
- (C) 1:4:16
- (D) 4:2:1

Extension: Explain your choice of answer.

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9.4.6.19 Two satellites are orbiting at the same altitude. Satellite X has three times the mass of satellite Y. What is the ratio of their orbital speeds?

- (A) $X:Y = 1:1$
- (B) $X:Y = 1:3$
- (C) $X:Y = 3:1$
- (D) $X:Y = 9:1$

Extension: Explain the difference in your answer if the satellites had the same mass.

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9.4.6.20 Which statement about the orbits of satellites is correct?

- (A) The greater the mass and altitude, the slower the satellite travels.
- (B) The greater the mass and altitude, the faster the satellite travels.
- (C) The higher the altitude of the orbit, the faster the satellite travels.
- (D) The higher the altitude of the orbit, the slower the satellite travels.

Extension: Which two choices are you able to eliminate straightaway and why?

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9.4.6.21 Three identical moons orbit planets P, Q and R which have masses M , $4M$ and $16M$. The moons all have the same orbital velocity. What is the ratio of their orbital radii?

- (A) 1:1:1
- (B) 1:2:4
- (C) 1:4:16
- (D) 4:2:1

Extension: If the moons had the same orbital radii, what would be the ratio of their orbital velocities?

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9.4.6.22 Satellite X is in a 300 km low Earth orbit while identical satellite Y is in a 1000 km low Earth orbit. Which statement about these two satellites is correct?

- (A) X is moving faster, and has more gravitational potential energy than Y.
- (B) X is moving faster, but has less gravitational potential energy than Y.
- (C) X is moving slower, but has more gravitational potential energy than Y.
- (D) X is moving slower, but has less gravitational potential energy than Y.

Extension: Justify both parts of your answer.

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9.4.6.23 Two satellites, X mass 2000 kg and Y mass 3000 kg are placed into orbits above Mars. The altitude of these orbits is two and three times the radius of Mars respectively. What is the ratio of their orbital speeds?

- (A) $X:Y = 1:1$
- (B) $X:Y = 3:1$
- (C) $X:Y = \sqrt{3}:2$
- (D) $X:Y = 2:\sqrt{3}$

Extension: Justify your answer.

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Answer Questions 9.4.6.24 to 9.4.6.40 on your own paper.

9.4.6.24 Calculate the orbital period of Deimos, one of the two moons of Mars. Its average distance from Mars is 23 400 km and its irregular shape averages about 13 km across. The mass of Mars is 6.42×10^{23} kg, and its diameter is 6794 km.

9.4.6.25 Calculate the altitude of an Earth satellite with a period of 12 hours. The mass of Earth is 5.974×10^{24} kg and its diameter is 12 560 km.

9.4.6.26 The table gives information about four of the moons of the planet Uranus. Use Kepler's law of periods to calculate the missing data in the table.

Moon	Radius of orbit (km)	Orbital period (Earth days)
Miranda	A	1.41
Ariel	190 900	B
Titania	C	8.71
Oberon	583 400	13.46

9.4.6.27 Geostationary satellites orbit with a radius of 42 260 km. Use this information to find:

- (a) The period of a satellite which orbits with a radius of 15 000 km.
- (b) The orbital radius of a satellite which has an orbital period of 4.0 hours.

9.4.6.28 A satellite has a mass of 500 kg and orbits at an altitude of 200 km. Calculate its orbital speed.

- 9.4.6.29** Calculate the orbital speed needed to keep a satellite in a stable orbit at an altitude of 1500 km above the Earth.
- 9.4.6.30** Three moons around planet X have masses M , $4M$ and $9M$.
- (a) If the moons are all the same distance from the planet's centre, calculate the ratio of their orbital speeds.
- (b) If the distances of these moons from the planet centre are R , $4R$ and $9R$ respectively, calculate the ratio of their orbital speeds.
- 9.4.6.31** Three identical moons are in orbit around planets of mass M , $4M$ and $9M$. The planets have the same radii.
- (a) If they have the same orbital speed, find the ratio of their distances from the planet centres.
- (b) If these distances are the same, find the ratio of their orbital speeds.
- 9.4.6.32** An Earth satellite has an orbital speed of 28 000 kph. Calculate its altitude.
- 9.4.6.33** The mass of Mars is 6.42×10^{23} kg and its diameter is 6794 km. Calculate the orbital speed needed to keep a Mars probe in a 200 km orbit.
- 9.4.6.34** Jupiter has a mass of 1.9×10^{27} kg. Its diameter is 142 984 km. Calculate the orbital speed needed to keep a Jupiter probe in orbit at 200 km.
- 9.4.6.35** Calculate the altitude that a satellite would orbit Jupiter if its orbital speed is 3×10^4 m s⁻¹.
- 9.4.6.36** The mass of the Sun is 1.99×10^{30} kg. Its diameter is 1 392 530 km. The diameter of Earth is 12 756 km. The distance between the Sun and the Earth is 150 000 000 km. Calculate the orbital speed of the Earth.
- 9.4.6.37** A 3000 kg satellite is orbiting Earth at an altitude of 250 km. Its orbital speed is 27 800 kph and the diameter of Earth is 12 756 km. Calculate:
- (a) The centripetal force acting on it.
- (b) Its centripetal acceleration.
- 9.4.6.38** A 150 kg satellite is orbiting Earth at an altitude of 272 km. Its orbital period is 90 minutes. Given that the diameter of Earth is 12 576 km, and its mass is 5.974×10^{24} kg, calculate the centripetal force on the satellite.
- 9.4.6.39** Imagine satellites orbiting Earth and Jupiter, both at altitudes of 2000 km. Compare their orbital velocities (qualitatively only) and account for the difference.

DOT POINT

ANSWERS



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AHL 9 Motion in Fields

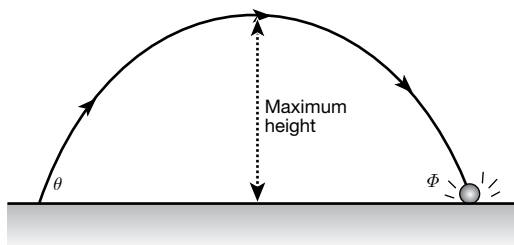
- 9.1.1.1** D Rate of rise or fall depends on acceleration due to gravity, not speed.
- 9.1.1.2** A Horizontal motion is constant motion. Vertical motion is uniformly accelerated motion. Horizontal and vertical motion components are independent of each other.
- 9.1.1.3** B If range is proportional to time elapsed, this means horizontal speed must be constant. This was one of Galileo's statements.
- 9.1.1.4** D
- 9.1.1.5** D Rocket becomes a projectile with constant velocity to the right and acceleration upwards – this is represented by the parabolic pathway D.
- 9.1.1.6** B
- 9.1.1.7** A
- 9.1.1.8** A
- 9.1.1.9** Horizontal component of its motion is constant velocity (zero acceleration), while the vertical component is accelerated by gravity.
- 9.1.1.10** Horizontal and vertical components of the motion of a projectile are independent of each other.
Horizontal component of its motion is constant velocity (zero acceleration).
Vertical component is constantly accelerated (by gravity).
- 9.1.1.11** Using Pythagoras,
At $t = 1$
 $17.92 = \text{vector sum of } v_y + 15$
So $v_y^2 = 17.92^2 - 15^2$
Therefore $v_y = 9.8 \text{ m s}^{-1}$
At $t = 2$
 $24.68 = \text{vector sum of } v_y + 15$
So $v_y^2 = 24.68^2 - 15^2$
Therefore $v_y = 19.6 \text{ m s}^{-1}$
At $t = 3$
 $33.01 = \text{vector sum of } v_y + 15$
So $v_y^2 = 33.01^2 - 15^2$
Therefore $v_y = 29.4 \text{ m s}^{-1}$
At $t = 4$
 $41.97 = \text{vector sum of } v_y + 15$
So $v_y^2 = 41.97^2 - 15^2$
Therefore $v_y = 39.2 \text{ m s}^{-1}$
So, change in velocity each second = 9.8 m s^{-1} , so acceleration is constant at 9.8 m s^{-2} which is consistent with Galileo's analysis.

9.1.2.1

- (a) Flight of projectile is symmetrical about its highest position.

The angle of elevation of its firing is equal to the angle of elevation when it hits the ground ($\theta = \phi$).

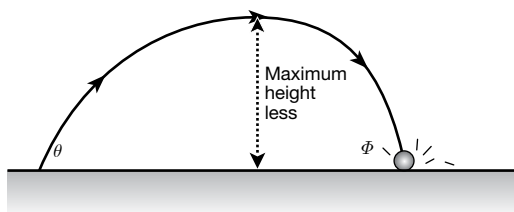
The speed at which it is fired will equal the speed at which it hits the ground.



- (b) Flight of projectile is not symmetrical about its highest position, the vertical velocity of the projectile will be more vertical as its flight continues.

The angle of elevation of its firing will be less than the angle of elevation when it hits the ground ($\theta < \phi$).

The speed at which it is fired will be greater than the speed at which it hits the ground. Note that both vertical and horizontal components will be less.



- (c) Air resistance will decrease both the vertical and horizontal components of the motion of the projectile and this causes the path to be different.

9.1.2.2

- (a) Range will be decreased (compared to no air resistance) as the horizontal component of its velocity will decrease as it travels due to air resistance.

- (b) Its time of flight will decrease because it will not rise as high due to air resistance against its motion.

- (c) Will be less than expected due to air resistance adding to the force of gravity to decrease its vertical velocity.

9.1.2.3

Angle θ will be less than angle ϕ because air resistance will decrease the horizontal components of the velocity of the projectile resulting in it landing at a steeper angle.

9.1.2.4

- (a) No. Air resistance will slow it down and decrease its range.

- (b) Increase the angle of elevation before it is fired. This will increase its range (up to 45° which is the maximum range elevation) and compensate for the effects of the air resistance.

9.1.2.5

- (a) The graph indicates that the horizontal motion of the projectile is constant, so air resistance would seem to be having negligible effect on the motion.

- (b) 0.75 m s^{-2}

9.1.4.1

- D 10.2 s

9.1.4.2

- D (A) and (B). The horizontal component of the projectile is 38.97 m s^{-1} and the resultant speed must be greater than this as will also have a vertical component (unless it is at the top of its flight, in which case the speed will be equal to the horizontal component).

9.1.4.3

- C Angle of elevation of the projectile after 2.0 s is 30° , so angle at launch must be greater than this, so choices (B) and (D) should be disregarded immediately.

9.1.4.4

- B Range and time of flight of a projectile are independent of their mass.

9.1.4.5

- A 1 Hz

9.1.4.6

- D They will both have a range of 251.2 m .

- 9.1.4.7** B Horizontal components will be the same, vertical component at R will be greater and in the opposite direction, overall velocity at R will be greater and in a different direction.
- 9.1.4.8** A 5.5 m s^{-1} at 62° down from the horizontal.
- 9.1.4.9** (a) 6.32 s
(b) 948.7 m
(c) 162 m s^{-1} at 22.5° down from the horizontal.
- 9.1.4.10** (a) 160 m s^{-1}
(b) 68.9 m
(c) Up at 164.2 m s^{-1} at 12.9° to the horizontal.
- 9.1.4.11** 115.5 m
- 9.1.4.12** All answers in order of information requested in the worksheet.
- 140 m s^{-1} , 140 m s^{-1} , 0 , 2100 m , 140 m s^{-1} , 147 m s^{-1} , 203 m s^{-1} at 46.4° to horizontal, 15 s , 1102.5 m , 143.1 m s^{-1} at 11.9° to horizontal, 980 m
 - 80 m s^{-1} , 80 m s^{-1} , 0 , 720 m , 80 m s^{-1} , 88.2 m s^{-1} , 119.1 m s^{-1} at 47.8° to horizontal, 9 s , 396.9 m , 85.2 m s^{-1} at 20.2° to horizontal, 274.4 m
 - 16.7 m s^{-1} , 16.7 m s^{-1} , 0 , 50 m , 16.7 m s^{-1} , 29.4 m s^{-1} , 33.8 m s^{-1} at 60.4° to horizontal, 3 s , 44.1 m , 33.8 m s^{-1} at 60.4° to horizontal, 0 m
 - 14.6 m s^{-1} , 14.6 m s^{-1} , 0 , 80 m , 14.6 m s^{-1} , 53.6 m s^{-1} , 55.6 m s^{-1} at 74.8° to horizontal, 5.5 s , 147 m , 32.8 m s^{-1} at 63.6° to horizontal, 24.5 m
 - 33.95 m s^{-1} , 33.95 m s^{-1} , 0 , 203.7 m , 33.95 m s^{-1} , 58.8 m s^{-1} , 67.9 m s^{-1} at 60° to horizontal, 6.0 s , 176.4 m , 44.9 m s^{-1} at 40.9° to horizontal, 53.9 m
 - 20 m s^{-1} , 20 m s^{-1} , 0 , 150 m , 20 m s^{-1} , 73.5 m s^{-1} , 76.2 m s^{-1} at 74.8° to horizontal, 7.5 s , 275.6 m , 35.6 m s^{-1} at 55.8° to horizontal, 153.1 m
 - 125 m s^{-1} , 125 m s^{-1} , 0 , 50 m , 125 m s^{-1} , 3.92 m s^{-1} , 125.1 m s^{-1} at 1.8° to horizontal, 0.4 s , 0.8 m , 0 , 0 m
 - 150 m s^{-1} , 150 m s^{-1} , 0 , 675 m , 150 m s^{-1} , 44.1 m s^{-1} , 156.3 m s^{-1} at 16.4° to horizontal, 4.5 s , 99.2 m , 152.9 m s^{-1} at 11.1° to horizontal, 0 m
 - 22.2 m s^{-1} , 22.2 m s^{-1} , 0 , 177.8 m , 22.2 m s^{-1} , 78.4 m s^{-1} , 81.5 m s^{-1} at 74.2° to horizontal, 8 s , 313.6 m , 36.8 m s^{-1} at 52.9° to horizontal, 191.1 m
 - 39.4 m s^{-1} , 39.4 m s^{-1} , 0 , 590.8 m , 39.4 m s^{-1} , 147 m s^{-1} , 152.2 m s^{-1} at 75° to horizontal, 15 s , 1102.5 m , 49.2 m s^{-1} at 36.7° to horizontal, 980 m
 - (a) 3.46 s
(b) 103.9 m
(c) 45.3 m s^{-1}
 - (a) 6.4 s
(b) 44.3 m s^{-1} at 89.2° down from horizontal
(c) 3.06 s
(d) 62.72 m s^{-1} at 89.5° (If you forgot to take the initial horizontal component into account your answer will be 62.610 .)
- 9.1.4.13** All answers in order of information requested in the worksheet.
- 20 m s^{-1} at 30° to horizontal, 17.3 m s^{-1} , 10 m s^{-1} , 35.3 m , 5.1 m , 1.02 s , 2.04 s
 - 30 m s^{-1} at 60° to horizontal, 15 m s^{-1} , 26 m s^{-1} , 79.5 m , 34.5 m , 2.65 s , 5.3 s
 - 35.6 m s^{-1} at 55.8° to horizontal, 20 m s^{-1} , 29.4 m s^{-1} , 120 m , 44.1 m , 3.0 s , 6.0 s
 - 57 m s^{-1} at 37° to horizontal, 45.4 m s^{-1} , 34.3 m s^{-1} , 318.2 m , 60.0 m , 3.5 s , 7.0 s
 - 258.5 m s^{-1} at 50° to horizontal, 166.1 m s^{-1} , 198 m s^{-1} , 6712 m , 2000 m , 20.2 s , 40.4 s
 - 296.9 m s^{-1} at 81.9° to horizontal, 41.7 m s^{-1} , 294 m s^{-1} , 2500 m , 4410 m , 30 s , 60 s
 - 200 m s^{-1} at 45° to horizontal, 141.4 m s^{-1} , 141.4 m s^{-1} , 4080 m , 1020.1 m , 14.43 s , 28.86 s
 - 150 m s^{-1} at 40° to horizontal, 115 m s^{-1} , 96.4 m s^{-1} , 2262 m , 474 m , 9.84 s , 19.67 s
 - 46.2 m s^{-1} at 60° to horizontal, 23.1 m s^{-1} , 40 m s^{-1} , 188.4 m , 81.6 m , 4.08 s , 8.16 s

10. 152.3 m s^{-1} at 74.8° to horizontal, 40 m s^{-1} , 147 m s^{-1} , 1200 m , 1102.5 m , 15 s , 30 s
11. 64 m s^{-1} at 50° to horizontal, 40 m s^{-1} , 50 m s^{-1} , 408.2 m , 127.5 m , 5.1 s , 10.20 s
12. 286.9 m s^{-1} at 25° to horizontal, 260 m s^{-1} , 121.2 m s^{-1} , 6433 m , 750 m , 12.37 s , 24.74 s
13. 400 m s^{-1} at 30° to horizontal, 346.4 m s^{-1} , 200 m s^{-1} , 14133 m , 2041 m , 20.4 s , 40.8 s
14. 176.1 m s^{-1} at 36° to horizontal, 143 m s^{-1} , 103 m s^{-1} , 3000 m , 540.2 m , 10.5 s , 21 s
15. 173.2 m s^{-1} at 58° to horizontal, 91.60 m s^{-1} , 147 m s^{-1} , 2748 m , 1102.5 m , 15 s , 30 s

9.1.4.14

All answers in order of information requested in the worksheet.

1. 49 m s^{-1} at 30° to horizontal, 42.4 m s^{-1} , 24.5 m s^{-1} , 396.9 m , 30.6 m , 2.5 s , 9.36 s
2. 25 m s^{-1} at 30.3° to horizontal, 21.6 m s^{-1} , 12.6 m s^{-1} , 138 m , 8.1 m , 1.3 s , 6.4 s
3. 101 m s^{-1} at 84.3° to horizontal, 10 m s^{-1} , 100.5 m s^{-1} , 200 m , 515 m , 10.3 s , 20 s
4. 50 m s^{-1} at 45° to horizontal, 35.4 m s^{-1} , 35.4 m s^{-1} , 387.2 m , 63.9 m , 3.6 s , 10.94 s
5. 15 m s^{-1} at 3.2° to horizontal, 14.97 m s^{-1} , 0.85 m s^{-1} , 59.9 m , 0.037 m , 0.087 s , 4.0 s
6. 31 m s^{-1} at 71.2° to horizontal, 10 m s^{-1} , 29.4 m s^{-1} , 76 m , 44.1 m , 3.0 s , 7.6 s
7. 35.1 m s^{-1} at 30° to horizontal, 30.4 m s^{-1} , 17.6 m s^{-1} , 158.1 m , 15.8 m , 1.8 s , 5.2 s
8. 40 m s^{-1} at 40° to horizontal, 30.64 m s^{-1} , 25.7 m s^{-1} , 300 m , 33.6 m , 2.62 s , 9.8 s
9. 65 m s^{-1} at 39.7° to horizontal, 50 m s^{-1} , 41.5 m s^{-1} , 500 m , 87.9 m , 4.2 s , 10 s
10. 66.6 m s^{-1} at 72.5° to horizontal, 20 m s^{-1} , 63.5 m s^{-1} , 300 m , 205.7 m , 6.5 s , 15 s
11. 23.6 m
12. (a) 37°
(b) 18.8 m s^{-1}
13. (a) 886.4 m
(b) 72.7 m s^{-1} at 47.6° to horizontal

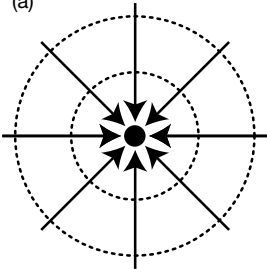
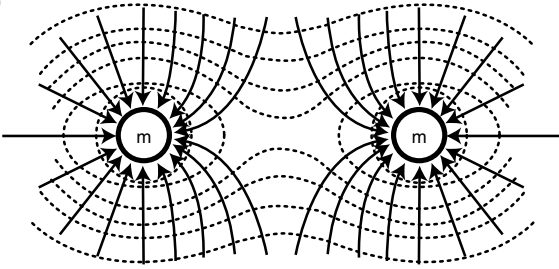
9.2.1.1 The gravitational potential at a point in a gravitational field is equal to the work done per unit mass in bringing a point mass from infinity to that point.

9.2.1.2 Gravitational potential energy at a point in a gravitational field is the energy a mass possesses due to its mass and its position in the gravitational field and is equal to the work done in moving the mass from infinity to that point.

9.2.1.3 It is only at infinity that the value of a gravitational field will be zero, so it is only at infinity that gravitational potential, or gravitational potential energy can be zero.

9.2.1.4 The absolute value of *GPE* is measured compared to a value of zero at infinity. Moving away from infinity, objects are considered to be falling into a gravity well, so their *KE* increases. From the law of conservation of energy, since their total energy at infinity (not moving) is zero, their *GPE* must decrease. To decrease from zero means to go into negative values.

- 9.2.1.5**
- (a) $E_p = -GM_em/R$
 - (b) $V = W/m$
 - (c) $V = -GM_e/R$
 - (d) From $F_g = mg = GM_em/R^2$ we get $g = GM_e/R^2$
 - (e) From (c) and (d) we get $gR^2 = GM_e = -VR$
Therefore $V = -gR = -GM_e/R$
 - (f) $W = mg\Delta h$
 - (g) Answers will vary, for example: The equation $W = mgh$ refers to the potential energy change of an object that is moved through a vertical displacement of h metres close to the surface of the Earth, so it is referring to a change in displacement relative to the surface of the Earth. It should therefore show this in symbolic form.
 - (h) Answers will vary, for example: Because the value of the gravitational field changes with distance from the centre of the Earth, the equation $W = mg\Delta h$ only holds for displacements close to the surface, whereas the equations in (b) and (e) not only hold for any position above the Earth, they can also be used for any mass at any position above any heavenly object provided the value of the gravitational field for that body is known at that position.

- 9.2.1.6** (a) Work is done by the gravitational field, so $W = F_g \Delta x = mg \Delta x = -m \Delta V$
 (b) $g = -\Delta V / \Delta x$
 (c) The gravitational potential between A and B is constant.
 (d) Gravitational field strength at a region in space is equal to the negative gradient of the gravitational potential at that region.
- 9.2.4.1** If the potential of any system is negative, then work has to be done in order to separate the objects in that system.
- 9.2.4.2** (a) $-2.37 \times 10^9 \text{ J}$
 (b) $-9.46 \times 10^6 \text{ J kg}^{-1}$
 (c) The negative sign indicates that the maximum value for both gravitational potential energy and gravitational potential is zero (at infinity) and is less than this, and therefore negative, at any other point.
- 9.2.4.3** The gravitational potential at all points on an equipotential surface is the same.
- 9.2.4.4** (a)  (b) 
- 9.2.4.5** Gravitational field acts directly downwards towards the centre of mass of a mass so gravitational field lines will be perpendicular to the surface of the mass. They must therefore be at 90° to equipotential lines otherwise there would be a component of the field parallel to the surface.
- 9.2.7.1** Escape speed is the speed an object must be projected vertically upwards from the surface of the Earth in order to be able to escape the Earth's gravitational field.
- 9.2.7.2** No. If a spaceship has its own engines and enough fuel, then it can propel itself upwards at any speed and it will eventually be far enough away from Earth that the gravitational field is effectively zero.
- 9.2.7.3** The work needed to be done on a spacecraft to project it outside the Earth's gravitational field will equal both the kinetic energy it has at launch and the gravitational potential energy it has when it has escaped the gravitational field, so
 $KE = E_p = \frac{1}{2}mv^2 = GM_p m / R$ (ignore the negative sign, only interested in absolute value)
 Rearranging this we get $v = \sqrt{2GM_p / R}$
- 9.2.7.4** From the formula for escape velocity, either the mass of Mars is less than that of Earth, or its radius is larger, or there is some combination of both these factors resulting in the smaller escape speed.
- 9.2.7.5** About 2378 m s^{-1} .
- 9.2.7.6** B A and D.
- 9.2.7.7** C
- 9.2.7.8** D
- 9.2.7.9** A
- 9.2.7.10** C The concept of escape velocity is that this is the velocity with which a projectile would need to be fired from the surface in order to escape the planet's gravitational field. A rocket under its own power can 'escape' at any speed as long as it is moving away from the planet.
- 9.2.7.11** For Mercury, mass/radius = 1.475×10^{17} , for Venus this ratio is 8.13×10^{17} , therefore this would indicate escape velocity for Venus is higher than escape velocity of Mercury. (From the equation, escape velocities for Mercury is 4424 m s^{-1} , for Venus it is $10\,393 \text{ m s}^{-1}$.)
- 9.2.9.1** C Satellite is going to higher altitude orbit, so work must be done on it against the pull of gravity. Therefore its E_p must increase.
- 9.2.9.2** B From the equation if the distance between the objects is halved, the gravitational potential energy between them is doubled, so the new gravitational potential energy will be $2.0E$, so an additional $1.0E$ of work has been done.

- 9.2.9.3** B The force of friction will work to reduce the speed of the satellite and then the force of gravity will pull it closer to the Earth, so, while both forces are needed to result in the orbital decay of the satellite, technically, it is the gravitational force which lowers the altitude of the orbit.
- 9.2.9.4** A
- 9.2.9.5** A The E_p of an object is zero at infinity and is a negative quantity anywhere else. It varies inversely with the distance from the centre of the Earth.
- 9.2.9.6** A
- 9.2.9.7** C E_p would be greater as object is further from Earth, so energy has to be put into it to increase its altitude.
- 9.2.9.8** C Initial E_p is $\frac{-GMm}{R}$, final E_p is $\frac{-GMm}{3R}$, which is one third of the original amount, but because of the negative sign represents an increase rather than a decrease, so E_p has been increased by two thirds. (It must be an increase since work has to be done on the satellite to boost it to a higher orbit.)
- 9.2.9.9** A If its gravitational potential energy has been increased, then it must be in a higher orbit and so work has been done on it by its engines rather than gravity.
- 9.2.9.10** B Yes, double since gravitational potential energy depends on the mass of the satellite.
- 9.2.9.11** B Less since the gravitational force of attraction of the Moon is only one sixth that of the Earth.
- 9.2.9.12** C Yes, double since gravitational potential energy depends on the mass of the satellite.
- 9.2.9.13** $-1.93 \times 10^{10} \text{ J}$
- 9.2.9.14** $+4.61 \times 10^9 \text{ J}$
- 9.2.9.15** Work is done on an object whenever an applied force causes a change in energy of the object. When a gravitational force (or an external force) causes an object to change its position in a gravitational field, then the work done by that force is equal to the gravitational potential energy the object loses (or gains).
- 9.2.9.16** (a) 1470 J kg^{-1}
(b) $3.38 \times 10^8 \text{ J}$ (or watts)
- 9.2.9.17** (a) $2.2 \times 10^{10} \text{ J}$
(b) $2.6 \times 10^{10} \text{ J}$
(c) $\text{J kg}^{-1} \text{ m}^{-1} = \text{kg m}^2 \text{ s}^{-2} \cdot \text{kg}^{-1} \text{ m}^{-1} = \text{m s}^{-2}$
(d) About 10.
(e) The strength of the gravitational field at the surface.
- 9.3.1.1** (a) The electric potential at a point in an electric field is equal to the work done per unit positive charge in moving it from infinity to that point.
(b) J C^{-1} equivalent to V.
- 9.3.1.2** The potential associated with a positive charge is taken as positive and that associated with a negative charge is negative.
- 9.3.1.3** (a) The electric potential energy between any two points in an electric field is equal to the negative of the work done by an electric field in moving a point charge between the two points.
(b) When a charged particle moves in an electric field, it either gains or loses kinetic energy (equal to the work done by the field or an external force if it moves against its natural direction in the field). In order to obey the law of conservation of energy, the electric potential energy of the charge must either increase or decrease. Therefore, the electrical potential is the negative of the work done.
- 9.3.2.1** $V = kq/r$ where $k = 9 \times 10^9 \text{ N m C}^{-2}$
- 9.3.2.2** (a) $-8.64 \times 10^{-3} \text{ J}$ (remember, work done $W = -qV$)
(b) $8.64 \times 10^{-3} \text{ J}$
(c) In (a) work must be done by an external force and will therefore be positive, so the work done by the field must be negative. In (b) work would be done by the field, and would therefore be positive.
- 9.3.2.3** 0.162 V
- 9.3.2.4** 900 V

9.3.3.1

Electric field lines around each →	Potential near each	Field intensity near each
(a)		
(b)		
(c)		
(d)		
(e)		

9.3.3.2

$$E = -\Delta V/\Delta x$$

9.3.3.3

(a) $\Delta W = F\Delta x$

(b) $\Delta W = -q\Delta V$

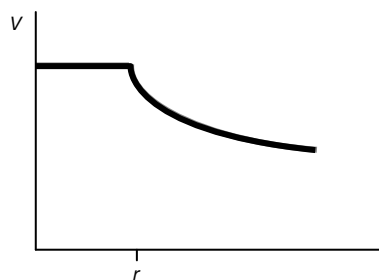
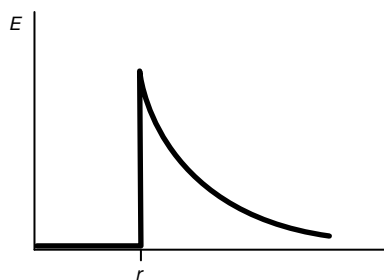
(c) $F = -qE$

(d) $E = -\Delta V/\Delta x$

(e) The potential gradient of an electric field is a measure of the rate at which the electric field strength changes with respect to distance, distance being measured in the direction in which the change is maximum.

(f) $V\ m^{-1}$

9.3.3.4



9.3.4.1

13.5 V

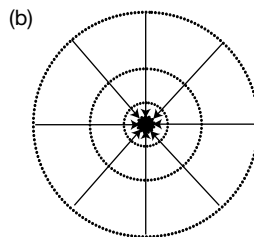
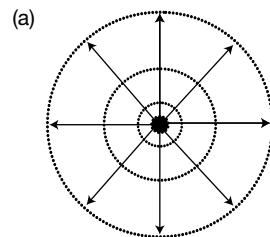
9.3.4.2

(a) 23.82 V (Electric potential at a point due to a charge, $V = kq/r$ and is a scalar quantity. Potential due to charge at X is -21.18 V and due to charge at Y is 45.00 V, net 23.82 V.)

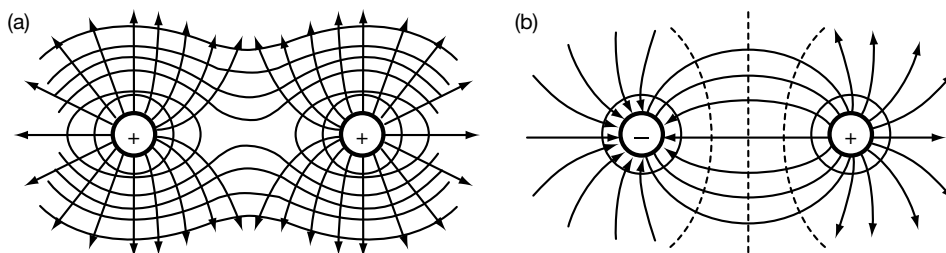
(b) 132 V

(c) It would not change.

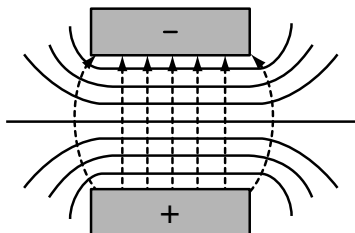
9.3.5.1



9.3.5.2



9.3.5.3



9.3.5.4

B

9.3.5.5

A

9.3.5.6

D

9.3.5.7

D Potential inside the sphere is constant, so there will be no potential lines, and potential outside the sphere varies as the inverse of the distance from the sphere, so the equipotential lines will get further apart with greater distance from the sphere (assuming they represent constant potential gradient).

9.3.6.1

Equipotential lines are always at right angles to field lines.

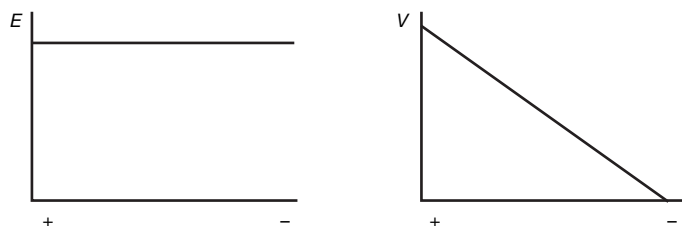
9.3.6.2

Equipotential lines represent positions of equal potential around a two-dimensional diagram of a charged particle while equipotential surfaces represent surfaces of equal potential in three dimensions.

9.3.6.3

- (a) Electric field inside the sphere is zero.
- (b) Electric field outside the sphere varies as $1/r^2$ from the sphere.
- (c) Electric potential inside the sphere is constant in value.
- (d) Electric potential outside the sphere varies as $1/r$ from the sphere.

9.3.6.4



9.3.7.1

C

9.3.7.2

C

9.3.7.3

A

9.3.7.4

B

9.3.7.5

- (a) $1.8 \times 10^{-3} \text{ J}$
- (b) The electric field around a positive charge works to move another positive charge away from it (repels it), so work will have to be done by an external force.
- (c) The electric field.

9.3.7.6

$5 \times 10^{-4} \text{ m}$

9.3.7.7

$5.6 \times 10^{-16} \text{ J} = 3500 \text{ eV}$

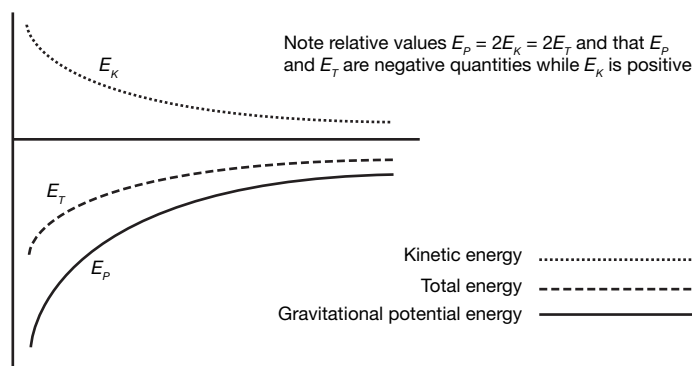
9.3.7.8

101 839 V

- 9.3.7.9** (a) The electric potential between the two charges $\Delta W = Fr = kQqr/r^2$
Therefore $V = kQq/r = 9 \times 10^9 \times 6 \times 10^{-6} \times 9 \times 10^{-6}/0.5 = 9.72 \text{ J}$
- (b) From the law of conservation of momentum
 $m_x v_x - m_y v_y = 0$ (initial momentum = 0)
From this, $v_y = m_x v_x / m_y$
From the law of conservation of energy (initial $KE = 0$)
 $\frac{1}{2} m_x v_x^2 + \frac{1}{2} m_y v_y^2 = 0$
Substituting for v_y from the momentum equation, and putting values in, we get
 $\frac{1}{2} \times 0.004 v_x^2 + \frac{1}{2} \times 0.012 \times (0.004)^2 v_x^2 / (0.012)^2$
from which $v_x = 60.4 \text{ m s}^{-1}$
- 9.3.7.10** (a) 25 V
(b) 25 V
(c) Zero
- 9.3.7.11** (a) From $W = QV = 40 \times 1.5 \times 10^9 = 6 \times 10^{10} \text{ J}$
(b) From $KE = \frac{1}{2} m v^2 = 6 \times 10^{10} = 0.5 \times 5000 v^2$
Hence $v = 4900 \text{ m s}^{-1}$ (4899)
(c) From $E = mc\Delta T = 6 \times 10^{10} = m \times 4.18 \times 80$
Therefore $m = 179.4 \text{ tonnes}$
- 9.3.7.12** 1260 V
- 9.3.7.13** 75 V
- 9.4.1.1** A centripetal force is one which acts towards the centre of rotation of a rotating object.
- 9.4.1.2** Answers will vary, for example:
1. Gravitational force acting on an orbiting moon, planet or artificial satellite.
 2. Frictional force between road and tyres causing car to turn corner.
 3. Tension in string towards centre of rotation as a stone tied to the end is whirled around in a circle.
- 9.4.1.3** The only force acting is the gravitational force.
- 9.4.1.4** (a) An object will be weightless only when the gravitational force acting on it is zero.
(b) The astronaut only *appears weightless*. He actually has weight because he is within the Earth's gravitational field, but, like his spaceship, he is in free fall towards the Earth and has no reaction forces acting on him. Hence he does not experience his weight.
- 9.4.2.1** The ratio of the period of an orbiting object to the cube of its orbital radius is constant (or vice versa).
- 9.4.2.2** Different derivations are possible, for example:
The centripetal force acting on an orbiting object is the gravitational force acting on it due to the object it is orbiting (the primary).
Therefore $m_o v^2 / rR = Gm_o m_{\text{primary}} / R^2$
From our equation for the average (and constant) orbital velocity of the object = distance travelled/time taken = circumference of orbit/period of orbit
Therefore $v = 2\pi R/T$
Substituting for v in the centripetal force equation we get $m_o (2\pi r/T)^2 / R = Gm_o m_{\text{primary}} / R^2$
Rearranging this, and eliminating m_o we get $R^3/T^2 = Gm_{\text{primary}}/4\pi^2 = \text{constant}$
- 9.4.2.3** (a) $3.36 \times 10^{18} \text{ m}^3 \text{ s}^{-2}$
(b) $1.01 \times 10^{13} \text{ m}^3 \text{ s}^{-2}$

- 9.4.3.1**
- (a) Gravitational potential, $V = -GM_e/r = g_o R_e^2/r = E_p/m$
 - (b) $F_G = GM_e m/r^2$
 - (c) $F_c = mv^2/r$
 - (d) $g_o = GM_e/R_e^2$
 - (e) Given gravitational potential $= -GM_e/r = E_p/m$
 Gravitational potential energy $= E_p = -GM_e m/r$
 And, given $g_o = GM_e/R_e^2$, and hence $GM_e = g_o R_e^2$
 Then, substituting for GM_e , we get $E_p = -g_o R_e^2 m/r$
 - (f) Knowing that kinetic energy $= \frac{1}{2}mv^2$
 and knowing that the gravitational force on the satellite is the centripetal force acting on it, we get
 $F_G = GM_e m/r^2 = F_c = mv^2/r$
 From this we get $mv^2 = GM_e m/r$, and therefore
 $E_K = \frac{1}{2}GM_e m/r$
 And using the same substitution for $GM_e = g_o R_e^2$ as above, we get
 $E_K = \frac{1}{2}g_o R_e^2 m/r$
 - (g) Regardless of the radius of the orbit the mathematical value of the kinetic energy of an orbiting satellite is half the value of its gravitational potential energy. Note the signs are opposite.
 - (h) Total energy $E_T = E_p + E_K = -g_o R_e^2 m/r + \frac{1}{2}g_o R_e^2 m/r = -\frac{1}{2}g_o R_e^2 m/r = -\frac{1}{2}GM_e m/r$
 Therefore $E_T = -\frac{1}{2}g_o R_e^2 m/r = -\frac{1}{2}GM_e m/r$
 - (i) Potential at surface of Earth $= -GM_e/R_e = -g_o R_e$
 Potential distance R from centre of Earth $= -GM_e/R = -g_o R_e^2/R$ (remember $GM_e = g_o R_e^2$)
 Therefore difference in potential between surface and a point at altitude R is
 $\Delta V = -g_o R_e^2/R - (-g_o R_e) = g_o R_e - g_o R_e^2/R = g_o R_e(1 - R_e/R)$
 - (j) Knowing that gravitational potential $V = -GM_e/r = g_o R_e^2/r = E_p/m$
 Gravitational potential energy, $E_p = Vm$
 Therefore change in gravitational potential energy $\Delta E_p = \Delta Vm = g_o m R_e(1 - R_e/R)$
 - (k) From the previous, work needed to lift satellite from the surface to altitude is
 $W = \Delta E_p = \Delta Vm = g_o m R_e(1 - R_e/R)$
- 9.4.4.1** A Projectile will be subject to gravitational acceleration so its KE will decrease as a function of v^2 . As it increases in altitude, the E_p of the projectile must increase in the same way as the KE decreases (law of conservation of energy). Since E_p is a negative quantity, as it increases, it will become less negative, approaching zero.
- 9.4.4.2** D Since thrust is constant, applied force will be constant and because mass is decreasing as fuel is used, acceleration will increase, so velocity will increase exponentially as will KE , so KE graph must rise. Since work is being done on the rocket continually, its E_p will also increase, again exponentially as altitude increases proportional to v^2 .
- 9.4.4.3**
- (a) From the equation for the kinetic energy of a satellite in orbit, $E_K = \frac{1}{2}g_o R_e^2 m/r$ we can see that $E_K \propto r^{-1}$, therefore graph is hyperbolic.
 - (b) From equation for the gravitational potential energy of a satellite in orbit, $E_p = -g_o R_e^2 m/r$ we can see that $E_K \propto r^{-1}$, therefore graph is hyperbolic.
 - (c) From equation for the gravitational potential energy of a satellite in orbit, $E_T = -\frac{1}{2}g_o R_e^2 m/r$ we can see that $E_K \propto r^{-1}$, therefore graph is hyperbolic.

9.4.4.4



- 9.4.6.1 B
- 9.4.6.2 C It would not change – the centripetal force is independent of the mass of the planet.
- 9.4.6.3 D The radius of the planet.
- 9.4.6.4 A No. The moon orbits the Earth not the Sun. The ratio is the same for all bodies orbiting the same primary.
- 9.4.6.5 A No. Period is not directly related to altitude.
- 9.4.6.6 A Orbital radius includes the radius of the planet whereas orbital altitude is height above the surface of the planet.
- 9.4.6.7 C No. Orbital radius includes the radius of the planet. This could only be the case if the radius of the planet was zero in this example.
- 9.4.6.8 A Choice (A) and (D) could be right – they both contain the number '8'. Examiners like to give answers like this – one correct, and the other incorrect but similar. However, the number of revolutions of planet Y is not going to be greater than 1, so answer could be, and is, (A).
- 9.4.6.9 D
- 9.4.6.10 C Net force can be zero regardless of the number of forces acting on the object.
- 9.4.6.11 B Weightlessness in this situation is only an apparent state – the astronaut is actually in free fall towards the Earth, and so has gravity acting on her. The astronaut can only be truly weightless when no forces act on her – as in deep outer space outside the influence of all gravitational fields, or if the net force acting on her is zero. She feels weightless, but is not actually weightless, hence the inverted commas to indicate the expression is incorrect.
- 9.4.6.12 B
- 9.4.6.13 B (A) would be correct for a geostationary satellite.
- 9.4.6.14 A Newton's first law of motion – an object will not change its state of rest or uniform motion unless an unbalanced force acts on it.
- 9.4.6.15 D The mass and radius of the planet.
- 9.4.6.16 B The gravitational force of the planet is incorporated into the value of the universal gravitational constant and the use of the planet's mass in calculating orbital speed. The greater the gravitational pull of a planet, the greater the orbital velocity needed to maintain a particular altitude orbit.
- 9.4.6.17 A Given the different masses and radii of the planets, the orbital velocities cannot be the same.
- 9.4.6.18 A Orbital speed is independent of the mass of the satellite and since all are at the same orbital radius, their orbital speeds must be the same.
- 9.4.6.19 A There would be no difference in the ratio if they are still at the same altitude. Orbital speed does not depend on the mass of the satellite.
- 9.4.6.20 D (A) and (B) because orbital speed is independent of the mass of the satellite.
- 9.4.6.21 C 1:1:1
- 9.4.6.22 B Orbital speed must be higher for a lower radius orbit since, from the equation, v is inversely proportional to orbital radius. Gravitational potential energy increases with height above the Earth, so higher orbit satellite has more E .
- 9.4.6.23 D Orbital velocity about a common primary (in this case, Mars) is dependent only on the distance of the objects from the planet's centre. In this case, 3 and 4 radii respectively.
- 9.4.6.24 133240.6 s = 37 hours

- 9.4.6.25** 20 229.2 km
- 9.4.6.26** A = 129 643 km
B = 2.51 days
C = 436 464 km
- 9.4.6.27** (a) 5.075 hours
(b) 12 798.6 km
- 9.4.6.28** 7782 m s⁻¹
- 9.4.6.29** 7111 m s⁻¹ = 25 600 kph
- 9.4.6.30** (a) 1:1:1 (orbital speed is independent of the mass of the moons)
(b) 6:3:2
- 9.4.6.31** (a) 1:4:9
(b) 1:2:3
- 9.4.6.32** 327.5 km
- 9.4.6.33** 3450 m s⁻¹ = 12 420 kph
- 9.4.6.34** 42 044 m s⁻¹ = 151 388 kph
- 9.4.6.35** 69 319 km
- 9.4.6.36** 29 671 m s⁻¹ = 106 818 kph
- 9.4.6.37** (a) 26 991.3 N towards the centre of the Earth.
(b) 8.98 m s⁻² towards the centre of the Earth.
- 9.4.6.38** 1350.8 N towards the centre of the Earth.
- 9.4.6.39** The orbital speed of the satellite around Jupiter would have to be greater than that of the satellite around Earth if both are to be in stable orbits because the gravitational pull of Jupiter is greater than that of Earth.